MAIN ENTRANCE OF THE YERKES OBSERVATORY.

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME V APRIL 1897 NUMBER 4

SPECTROSCOPIC NOTES.

By W. W. CAMPBELL.

THE HARVARD STAR, Z CENTAURI.

In December 1895, the *H. C. O. Circular* No. 4 announced that a "new star" had just been discovered by Mrs. Fleming, from an examination of the Draper Memorial photographs taken at Arequipa, Peru. The *Circular* stated that the star was situated very near the nebula *N. G. C.* 5253; that no trace of the star could be found on 55 plates taken from 1889 May 21 to 1895 June 14; that its magnitude on 1895 July 8 and July 10 was 7.2, and on 1895 December 19 was about 11; that an examination with a prism on December 19 showed that the spectrum was monochromatic, and closely resembled that of the adjacent nebula; and that, like the new stars in Cygnus, Auriga and Norma, this star appeared to have changed into a gaseous nebula.

The star was at once observed at Mt. Hamilton. It was found to follow the nucleus of *N. G. C.* 5253 by $1^s.4$ and was north of it $18''$. Its position for 1875.0 was[1]

$$\alpha = 13^h\ 32^m\ 51^s.9, \quad \delta = -30^\circ\ 59'\ 58''.$$

On the nights of 1895 December 22 and 29 I examined the

[1] *Ast. Jour.*, **16**, 85.

spectrum of the star—then 11.2 magnitude—and was reasonably certain the spectrum was continuous, but the seeing was too poor to permit a definite decision. It was certainly not nebular. On the morning of February 8, 1896, the conditions were good, and I carefully examined the spectra of the star and the adjacent nebula, using the large spectroscope and 60° crown prism. The nebula's spectrum was of the usual type, the lines at λλ 5007, 4959 and 4862 having their usual relative intensities. The line near λ 4690 seemed to be present, as in the case of *N. G. C.* 7027 and *G. C.* 4964. The spectrum of the Harvard star was *continuous*, though very peculiar. The maximum visual intensity was in the yellow-green, the green-blue was very faint, while the blue was surprisingly strong. In fact, the blue was very much brighter visually than the green-blue. The spectrum was relatively very faint from about λ 5200 to λ 4600. There was no trace of the nebular lines visible, nor of the *Hβ* line. There was some evidence of bright lines or of irregularities in the brightest portions of the spectrum, but the light was too weak to enable me to decide. The slit was at right-angles to the line joining the star and the nebula. By pressing against the telescope the two spectra were alternately brought into view. The nebular spectrum thus formed a good basis of comparison, and the star spectrum in no wise resembled it.

The Harvard observation of the spectrum was made on December 19 with the 15-inch telescope, when the star was of the 11th magnitude, very low in the sky and near the Sun. The continuous spectrum under such circumstances would be exceedingly faint. The star and nebula are less than 30″ apart. Is it not possible that the observed spectrum was that of the nebula, and not that of the star?

On June 11, 1896, Professor Hussey observed that the star had decreased in brightness to 14.4 magnitude, and that it was surrounded by a faint, irregular nebula which seemed to extend continuously to the main nebula south preceding. On July 9 he observed the star to be of the 16th magnitude, and the nebulosity surrounding it was plainly seen to be continuous with the

bright adjacent nebula, *N. G. C.* 5253. That the nebulous background was not seen earlier was probably due to the overpowering light of the star. On January 4, 1897, Professor Hussey looked for the star, without success: it was fainter than 16¼ magnitude, and invisible.

Some writers have contended that this star is not a "new star," but that it is identical with *Cord. DM.*−31°10536,[1] observed on four nights in 1885–92 at Cordoba. While I do not want to enter upon a discussion of this question—at present unsolved and not now capable of solution, apparently—I may perhaps express my opinion that all the evidence available points to the identity of the nebula *N. G. C.* 5253 and the star *Cord. DM.*−31°10536. The evidence that the Harvard star was observed previous to 1895 July 8 is confined to the single Cordoba date, 1887 April 12.

If the star is simply a variable, as some writers contend, its period must be very long, or its variations very irregular.

If the star is to be classed with the "temporary" stars, it is not analogous to the new stars in Cygnus, Auriga and Norma, but rather to the star of 1885 in the Andromeda Nebula.

THE SPECTRUM OF MARS.

My visual spectroscopic observations of Mars and the Moon in 1894, under extremely favorable circumstances, led me to conclude that the two spectra were apparently identical, so far as visual estimates of the intensities of the telluric lines were concerned. My paper on the subject stated the conclusions to be drawn from the observations as plainly as it would be possible even now to state them. Nevertheless, they were misunderstood persistently by many reviewers, and I beg to re-state them here, viz.:

While the polar caps are conclusive evidence of the presence of atmosphere and vapor (probably water-vapor) on Mars, yet these do not seem to exist in sufficient quantities to have been detected by any spectroscopic observations thus far made; and

[1] *Ast. Jour.* 16, 16, 106, 165, 166.

my observations indicate that the density of the atmosphere at the surface of Mars is not more than half as great as the density of our atmosphere at the summit of the Himalaya Mountains.

Thus far, all the observations were visual, though there were plates sensitive to the light from the region of the important δ vapor band. In March 1895 I obtained a few photographs of the spectra of Mars and the Moon, on Cramer's isochromatic plates, using the large Brashear spectroscope and a 60° crown prism. The photographs covered the region of the δ band. There was no visible difference in the spectra of the two objects, though the conditions were not first-class.

On October 22, 1895, using the apparatus described above, I obtained a long series of photographs of both spectra. The dew-point for the night was 0° Centigrade. Some of the negatives were copied on lantern-slide plates, for the purpose of increasing the contrasts in the spectra. Neither the original negatives, nor the positives on slow plates, revealed any differences in the two spectra. However, a comparison of the plates corresponding to high and low altitudes, convinced me that the photographic method *with low dispersion* is not so sensitive as the visual method with the same dispersion. On December 18, 1896, I obtained a few photographs, using a fourth-order grating. It was necessary to use a rather wide slit, and the negatives were considerably underexposed, though comparable in the δ region. There was no visible difference in the spectra, but the result is purely negative, for two reasons: (*a*) The negatives are not as dense as they should be; and (*b*) I was unable to secure photographs at low altitudes, to test the sensitiveness of the method. I believe the photographic method with high dispersion is fully as sensitive as the visual method with low dispersion; but to what extent it is more sensitive I cannot say. A train of three flint prisms would have been much more efficient than the grating, but such a train was not available.

There has been some discussion as to whether high or low dispersion should be used in such a problem as this. Not to enter upon a consideration of the general question, I may per-

haps make one or two remarks. In the photographic study of a spectrum, such as that of Mars, the question of brightness does not enter, except as it affects the exposure time. When the visual method is used, the question of brightness does enter. It is then a question of getting *a little something* with low dispersion, or *nothing at all* with high dispersion. It has been my experience that those who have not observed spectra at night invariably overestimate the brightness of those spectra.

COMET 1895 IV (PERRINE).

Visual observations on November 17, 1895, showed the yellow, green and blue bands of carbon, with their usual relative intensities, together with a strong continuous spectrum.

A photograph taken December 8, 1895, showed the following features:

The blue carbon band, unresolved, maximum near λ4690.

λ4366 bright line, easy.
λ4313 " " faint.
λ4298 " "
λ4214 " " very easy, cyanogen.
λ4196 " " easy, cyanogen.

Traces of several bright lines between λλ4100–4000 (cyanogen?).

λ3881 brightest line on plate, cyanogen.
λ3870 very bright line, cyanogen.

Continuous spectrum between λλ4700–4000, which has a fluted appearance, as if caused by the principal groups of absorption lines in the solar spectrum, notably the group at G.

COMET 1895 V (BROOKS).

On November 22, 1895, visual observations showed that the spectrum was of the usual character. The spectrum was too faint to photograph.

COMET 1896 I (PERRINE).

On February 19, 1896, the visual spectrum was of the usual character. A photograph recorded the bright cyanogen lines

at λλ 3881 and 3870. No other lines were recorded, on account of the faintness of the comet, which was not visible to the naked eye.

COMET 1896 III (SWIFT).

On April 30, 1896, the visual spectrum was of the usual char acter. The spectrum was too faint to photograph.

COMET 1889–96 (BROOKS-JAVELLE).

Visual observations were made on August 15, and October 6, 1896. The comet was about 13th magnitude. The continuous spectrum was plainly visible, and I was pretty certain that a trace of the green carbon band was visible, but not absolutely certain. There was no doubt that the continuous spectrum was relatively much stronger than the gaseous carbon bands in this comet, than in any of the other comets I have observed, except in the case of Holmes' comet of 1892.

These comet photographs and many of the visual observations, were made with the 12-inch telescope and the large Brashear spectroscope mounted in a wooden case, using a 60° crown prism. This combination is very effective for photographing comet spectra, except that the clock and slow motions are unsatisfactory, and render the guiding very difficult. Further, this combination permitted me to make the observations without interfering with the regular spectroscopic work in the large dome. An extensive and expensive equipment is not necessary for the study of comet spectra, and the subject is seriously neglected. I desire especially to call attention to the importance of observing the spectra of periodic comets, both visually and photographically, at every opportunity. It is a good working hypothesis that the continuous spectrum is relatively stronger in periodic comets than in parabolic ones. As a comet approaches the Sun, its more volatile constituents are excited, electrically or otherwise, and are probably driven off permanently from the mass of the comet. For a parabolic comet this effect would be temporary, while for a periodic comet it would go on constantly, under

the Sun's influence; in which case it would seem that the bright-line spectrum of a periodic comet should gradually become less prominent. This view is supported by the observed spectra of Comet III, 1892 (Holmes) and Comet 1889–96 (Brooks-Javelle), and possibly by the meagerness of carbon in meteorites.

The four comet spectra which I have thus far been able to photograph, viz.,

1893 II (Rordame),
1894 II (Gale),
1895 IV (Perrine),
1896 I (Perrine),

have been identical so far as the different intensities of the four permitted comparison. All were parabolic comets.

NOVA AURIGÆ.

Occasional observations for the magnitude of the new star of 1892 in Auriga have been made. No change in brightness has been recorded since 1892.

In Vol. I., No. 1, of this JOURNAL I called attention to the remarkable changes going on in this star's spectrum. It was shown that the bright lines λ4360 and λ5750 which were very bright in August 1892 had become very faint in 1894. No photographs have been secured since November 1894, but visual observations show that the change in the line λ5750 has been progressive. The observed intensities of six of the principal bright lines have been as follows:

	Hγ	λ4360	*Hβ*	λ4960	λ5010	λ5750
1892 August and September.....	0.1	0.8	1	3	10	1
1894 May 8.....	0.1	0.3	1	3	10	0.4
1894 September 7.....	0.1	0.2	1	3	10	0.4
1894 November 28.....	0.1	0.1	1	3	10	0.3
1896 August 15.....	—	—	1	3	10	0.1
1896 October 6.....	—	—	1	3	10	0.1

At the date of the last observation the line λ5750 was difficult to see at all.

It is especially significant that the lines λ4360 and λ5750 should be the ones to change. The first measures of the spectrum in August 1892 showed unmistakably that it was the spectrum of a nebula. At first, however, the lines λ4360 and λ5750 did not seem to exist in the old nebulæ. But photographs of their spectra at once showed the line λ4360 in five well-known nebulæ, and visual observations showed the line λ5750 in three nebulæ. These lines were strong in the *Nova*, but relatively faint in the old nebulæ. They have now become relatively faint, in fact practically invisible, in the *Nova*. The spectrum of the new star has lost its anomalies: it is now of the ordinary type of nebular spectrum, save that the lines remain broad, as they have always been described.

As my apparatus has been arranged, it has not been convenient to re-measure the wave-lengths of the principal nebular lines since November 1894. The last few measures secured were made with a dense 60° flint prism and magnifying power 26—a combination much preferable to the grating and low power employed in the earlier measures.

While the spectroscopic observations of *Nova Aurigæ* show it to be ***truly nebular***, there has been a question as to whether the nebulosity is ***actually visible*** in the focal image of a telescope.

When the reappearance of the *Nova* was observed on August 17, 1892 by Messrs. Holden, Schæberle and Campbell, "all the observers agreed that its appearance was different from that of other stars of the same magnitude."[1] Later Professor Barnard announced[2] that the object was "really a small bright nebula with a 10th magnitude nucleus. . . . . With the micrometer the nebulosity was found to be 3″ in diameter—a fainter nebulosity still surrounded this and was perhaps ½′ in diameter."

Mr. Newall suggested[3] that the nebulous appearance was not real, but was due to the chromatic aberration of the object-glass, and that the image was truly stellar. This suggestion was

[1] *A. and A.*, **11**, 715.

[2] *A. and A.*, **11**, 751.

[3] *Nature*, **46**, 489.

repeated and carefully elaborated by Professor Vogel.[1] Dr. Huggins,[2] observing with a reflecting telescope, which is free from chromatic aberration, saw the image as a stellar point.

The focal image of the *Nova* in the 36-inch telescope certainly looked substantially as Professor Barnard described it.[3] But further consideration of the problem, together with actual experiments on the *Nova* and on the Wolf-Rayet star +30°3639,[4] soon convinced me that the 36-inch telescope, with its strong chromatic aberration, was not suitable for deciding this question definitely. For if any one of the numerous monochromatic images were brought into focus, all the others would be out of focus, and would combine to form a halo surrounding the central image. The yellow image at λ5750, so long as it remained bright, augmented the difficulty.

I therefore determined to estimate the diameter of the *Nova* by observing the width of its spectrum. Observations for that purpose were made in the fall of 1893 and of 1894. The rather coarse micrometer wire was placed lengthwise of the spectrum, and its width was such as just to occult the principal nebular line when the atmospheric conditions were fair. From the known width of the wire and the proportions of the spectroscope and telescope, the angular width of the wire was computed to be 1½ seconds of arc. On none of the nights utilized was the seeing perfect; but I attempted to eliminate the effect of imperfect seeing by observing, in the same manner, the continuous spectrum of a star so selected that its spectrum at λ5010 and the principal nebular line would be of about equal intensities. In every case the two spectra were practically of the same width, thereby indicating that *the focal image of Nova Aurigæ is stellar.* At the same time it must not be forgotten that *Nova Aurigæ* is a true nebula: the spectroscopic evidence is indisputable.

[1] *Über den neuen Stern im Fuhrmann*, Berlin, 1893.

[2] *A. and A.*, 13, 314–315.

[3] *A. and A.*, 12, 419.

[4] This star has a hydrogen atmosphere, 5″ in diameter. *A. and A.*, 13, 461.

The publication of these observations of the *Nova* has been unduly delayed—at first from a desire to repeat them on a first-class night, and later by the hope that the 36-inch Crossley reflector would be available for repeating them. As soon as the reflector is available I shall endeavor to get its testimony on this interesting question.

LICK OBSERVATORY,
UNIVERSITY OF CALIFORNIA,
March 3, 1897.

ON THE SPECTRUM OF HYDROGEN.

By H. KAYSER.

IN the Harvard College Observatory *Circular* No. 16 I see that Professor Pickering has come to the conclusion that the lines he discovered in the spectrum of ζ Puppis belong to hydrogen, because he is able to represent the old hydrogen series and the new lines by one formula as a single series. This possibility shows better than anything else could do the correctness of my former statement, that the old hydrogen series and the new one end at nearly the same point. But I am sure that the representation of the two series as a single one is incorrect. My arguments are the following:

1. The analogy with all the other elements, which have two series ending at the same point in the spectrum.

2. The different appearance of the lines of the two series; in every true series the lines have the same character, and become fainter as the shorter wave-lengths are approached.

3. The different conditions of appearance; this difference is so great, that we are hitherto unable to produce the second series.

4. For all the elements the second constant in our formula $\frac{1}{\lambda} = A - Bn^{-2} - Cn^{-4}$ has nearly the same value, so nearly indeed, that Rydberg believed the value to be exactly the same. But if we unite the two hydrogen series, then this constant has for hydrogen a value four times greater than for any of the other elements.

All these arguments seem to show conclusively that we must assume two series in the spectrum of hydrogen; it then corresponds admirably with the other elements.

BONN, February 2, 1897.

THE CAUSE OF THE DARKNESS OF SUN-SPOTS.

By J. EVERSHED.

THE most generally received doctrine as to the constitution of the Sun is probably that in which the entire internal mass of that body is regarded as being in a gaseous condition; the temperature, below the photospheric layer, being above the critical point of all known substances. The low mean density is accounted for by supposing that the temperature increases rapidly with the depth below the surface, the expansive energy of the internal gaseous nucleus largely counteracting the enormous force of compression due to gravity.

It appears to be pretty generally admitted, too, by recent writers, that the photosphere is a surface of condensation; a region, exposed to the cold of space, where elements of high boiling point, such as those of the carbon group, are precipitating from the gaseous state and forming clouds of highly emissive solid or liquid particles.

I propose in this paper to discuss the question as to the cause of the relative darkness of Sun-spots on the basis of these fundamental ideas, and with special reference to the recent work of W. E. Wilson on the "Thermal Radiation of Sun-spots."

Most spot theories in vogue at the present time attribute the blackness of spots to masses of relatively cool vaporous material which absorbs the intense light of the underlying photosphere. Thus in Secchi's theory a spot is regarded as a kind of sink in the photosphere, into which the materials which have been erupted in the neighborhood are settling down again into the body of the Sun, forming a great cloud of cool absorbing vapors. Faye believes spots to be vortices set up by the relative drift of adjacent portions of the photosphere, the dark absorbing material accumulating in the vortex by reason of the indraught. Oppolzer likens a spot to a disturbed region in our atmosphere in which great contrasts of temperature arise; and he explains the

obscurity in the same way as a result of increased absorption by relatively cool vapors.

Many other theories have been proposed in which absorption is regarded as the principal factor in causing the darkness, and the evidence afforded by the spectroscope seems always to have been taken as practically demonstrating the truth of this hypothesis.

But absorption as ordinarily understood is in many respects very difficult to reconcile with the common features of spot formation. The well-defined structure and abrupt transitions in passing from photosphere to penumbra, and from penumbra to umbra, points rather to the *absence* of the bright photospheric clouds from the spot, than to their suppression beneath a mass of absorbing material; and seems much more suggestive of an actual rent in the photospheric layer through which a less luminous region is revealed.

Quite recently in a paper on the "Level of Sun-spots,"[1] read before the British Astronomical Association, Mr. Maunder argues that absorption can have but little effect in causing the spot darkness, for whether the spot be regarded as a depression or an elevation compared with the photosphere, the obscuring effect of an absorbing layer would be vastly increased when near the Sun's limb as compared with its effect at the center of the disk, owing to the foreshortening; and the greater the area of the spot the more noticeable would this become, so that in many cases the entire spot would appear as black as the umbra when near the limb. As this is not the case at all, the conclusion is drawn that diminished radiation rather than increased absorption is mainly operative in a spot.

In the same paper Mr. Maunder suggests that a spot may be regarded as a region of high temperature in which the condensation of highly incandescent carbon does not take place to the same extent as in the photosphere, the diminished radiation being due to the relatively low emissive power of the gaseous contents of the spot; just as in an ordinary gas burner the pre-

[1] *Jour. B. A. A.*, 7, No. 3.

cipitation of solid carbon produces a bright luminosity, whilst the purely gaseous portion of the flame glows but feebly.

This explanation of spot darkness certainly harmonizes very well with the observed structure of spots and with many of the attendant phenomena, such as the great brilliancy of the faculous bridges and the surrounding faculous region; the intensification of the H and K lines and frequently of the hydrogen lines over the entire spot region; all of which suggest that a spot is really a center of relatively high temperature.

Unfortunately it is open to a very serious objection when we consider the application of Kirchhoff's law to solar conditions. For suppose we liken a spot to a non-luminous Bunsen flame, or better, to a pure hydrogen flame burning in air, and a bright facula bridging the spot to a platinum wire held in the flame. The analogy would at first sight appear to be a very striking one, the hydrogen flame emitting a very feeble continuous spectrum and the glowing solid a very brilliant one, although no hotter than the flame. But yet according to Kirchhoff's law the feeble emissive power of the gas is exactly compensated by its feeble absorptive power, so that if we were to increase the thickness of the non-luminous flame indefinitely the brightness would increase, until finally, it would equal that of the glowing solid; even that of a theoretically "black" solid which has the highest emissive power. This condition would be reached when the radiating gas was of such thickness as to be entirely opaque to transmitted light.[1]

In the case of the Sun-spot, therefore, we should expect that the immense and practically unlimited depth of the interior gases would compensate for their relatively feeble radiating power, even if we took no account of the much higher temperature and high state of compression of the interior regions. There seems to be no escape from this difficulty, even if we imagine the interior of the Sun to be absolutely non-luminous, for then,

[1] The cumulative effect of a great thickness of radiating gas can easily be shown with a row of Bunsen flames such as are used in tube furnaces. If these are observed "end on" the brightness is seen to increase in proportion to the number of flames, or very nearly so.

according to Kirchhoff, it will also be absolutely transparent, and the photosphere on the opposite side would be seen through the spot opening.

Again, if the internal gases are so compressed as to be practically opaque like solids, then they must radiate like solids, they cannot continue to accumulate the energy acquired by absorption indefinitely. Thus we seem driven back again to some modification of the absorption hypothesis, unless we find that the ordinary laws of heat exchange are not applicable under solar conditions.

The structural characteristics of spots might perhaps be explained on the absorption hypothesis by supposing that the cooled absorbing material was situated at a considerable depth, being partly overlaid and encroached upon by the photosphere, the spot opening being at the same time filled up with dark material; and it would be natural to suppose this absorbing material to be the same as that which everywhere covers the Sun, producing the absorption at the limb, and giving rise to the mottled appearance of the disk due to variations in level of the photospheric clouds in this smoke-like veil. Thus there would be no real distinction to be drawn between a well-developed spot and the minute pores and interspaces between the photospheric clouds. It will be shown later, however, that there is a very marked difference in the character of the spot darkening and the general shading at the limb. It is clear that if a spot is really an accumulation of absorbing vapors it must be cooler than the photosphere, whilst if on the other hand, it is an opening where the photospheric clouds have been evaporated, we must regard it as being as hot as or hotter than the surrounding region. Evidence in support of the absorption hypothesis has been frequently derived from the widened lines seen in spot spectra, which are supposed to indicate a lower temperature in the absorbing gases. But the widening is at the most very slight; a proportionally slight increase in the depth of the gases concerned will equally well account for it. Furthermore, only a very small proportion of the lines in the spectrum are widened

or intensified; probably many others are weakened, or suppressed altogether even when they do not appear as *bright* lines. It has not, perhaps, been sufficiently realized that a large proportion of the light we are dealing with in the spectrum of a dark nucleus is not derived from the spot at all, but is simply photospheric light reflected from the sky; the contrast between the umbra and the sky illumination outside the limb being in many cases almost inappreciable. Thus the majority of the Fraunhofer lines in the umbral spectrum may be spurious lines; could we remove our atmosphere and wholly isolate the umbral light, it is quite possible that the spectrum would be found to be, in the main, an emission spectrum.

However this may be, the widened lines are evidently not a satisfactory criterion as to the relative temperature of spots and photosphere, and the slight extra amount of gaseous absorption implied by their presence can have practically no effect on the darkness of spots. This is obviously due to the general darkening, which is apparently continuous all along the visible spectrum, and may or may not be the result of absorption. The resolution of a portion of the spot band by Professor Young into innumerable closely crowded dark lines with occasional bright intervals,[1] would seem to point to absorption, but absorption by gaseous rather than solid or liquid matter.

In the opinion of the writer, no satisfactory explanation of spot darkness is likely to be arrived at until the spot band itself has received the closest investigation, both in the visible and invisible regions of the spectrum, particularly with regard to the relative intensity and character of the band and quite apart from the question of widened lines or bright lines, which can only give information as to the condition of the gases in the overlying reversing layer and chromosphere, and which taken all together can have but little influence on the general radiation of the spot.

THE THERMAL VALUE OF THE SPOT RADIATION.

The measurements of total radiation from spots by Langley,

[1] YOUNG, *The Sun*, 4th ed., p. 323.

using a bolometer, and recently by W. E. Wilson with a radiomicrometer, do not give any direct information as to the relative temperatures of photosphere and spots; the relative emissive powers being unknown. Indirectly, however, they would seem to afford a clew.

In the thermal measuring apparatus the blackened receiving surface may be supposed to absorb indiscriminately all the radiant energy falling upon it, whatever the wave-length, that is, the whole range of wave-lengths, including of course the visible rays. Thus the measurements sum up the energy in the entire spectrum, and show, as it were, the *average* darkness of the spot band when the whole spectrum is taken into account.

The results show that a spot is very much less dark measured thermally than visually. The spot band is, therefore, much darker in the visible region of the spectrum than it is in other regions; where, it would seem, it may even be *reversed*. This fact is the more striking, when we consider that in ordinary sunlight the rays which possess the maximum heating power are those about the middle of the visible spectrum, so that one would expect, *a priori*, to find a practical agreement between thermal and photometric estimates of the darkness.

Referring to Mr. Wilson's paper (*Monthly Notices*, Vol. LV, No. 8), the monthly mean values of the umbral radiation are found to vary from .35 to over .50; that of the photosphere at the center of the disk being 1.00. The photosphere radiation, however, rapidly diminishes from the center towards the limb where it becomes .45, whilst the spot radiation remains nearly constant in all positions on the disk. Thus the ratio between the radiation of the spot and that of the *neighboring* photosphere approaches unity as the spot nears the limb. The highest value of this ratio recorded by Mr. Wilson is .83, but both Langley and Frost have measured spots in which the thermal intensity even exceeded that of the surrounding photosphere.

With regard to the visible radiation of spots, it is quite obvious from ordinary telescopic observation that the umbra of a normal spot does not emit more than a very small fraction of

the light of the photosphere, even of the neighboring photosphere, when the spot is near the limb. To make sure of this point the writer has roughly estimated the relative darkness of a spot by means of an Abney photometer, so arranged as to reduce the light of any portion of the photosphere by any known amount The results obtained show that the *penumbra* of an ordinary spot is not more than one-third or one-fourth as bright as the photosphere; whilst the umbra itself is probably in most cases less than one-twentieth.

The apparatus being incapable of measuring small fractions, this latter value is probably an upper limit, the intensity may have any value less than that; many spots must indeed be at least a hundred times less bright than the neighboring photosphere at the limb, for in this position the dark umbra often presents the illusion of a piece cut out of the limb; proving that no more light comes from the spot than from the sky outside. Perhaps the average spot nucleus is not however quite so dark as this, for during partial solar eclipses spots are said to appear lighter in tint than the black disk of the Moon.

But whatever may be the true photometric value of the spot darkness the discrepancy between thermal and visual estimates is evidently very marked, and it would be of great interest to determine in what region of the spot spectrum the extra energy is to be found, which is shown by the relatively high thermal value of the radiation. Does the spot band become less dark or even reversed, in the infra-red or in the ultra-violet?

The question of the relative temperature of spots and photosphere must largely depend on the position in the spectrum of this region of maximum intensity. For suppose we admit that the whole of the Sun's interior below the photosphere behaves like an opaque solid as regards radiation. The emission spectrum will be a continuous one; but the distribution of energy in the spectrum will not be uniform. The wave-length of the rays of greatest intensity will depend on the temperature, the wave-length decreasing with increase of temperature according to a well-established law of radiating solids. Now the temperature

of the photosphere is such as to give, according to Langley, a maximum in the visible spectrum. But deep down in the interior the temperature must be enormously higher and the wave-length of maximum energy from that region must be shifted far into the ultra-violet.

If then in a spot we have a glimpse of the interior intensely hot regions below the photosphere we should expect to find the spot spectrum brighter (or less dark) in the ultra-violet. But if relatively cool absorbing vapors are the principal cause of spot darkness, then the maximum should be found in the infra-red; not a true emission maximum perhaps, but a part of the spectrum where the absorption has less influence than in the visible spectrum.

There is one point which would seem to be definitely settled by the thermal measures. It has been previously mentioned that the spot darkness and the general shading at the limb are different in character. This results from a comparison between the thermal and visual estimates of the darkening in the two cases. In the limb absorption the discordance between these measures is not greater than would be the case assuming it is due to a smoke-like layer which absorbs the blue rays more completely than the red and yellow, which in sunlight have the greater heating power, a feature too that is well brought out by Vogel's detailed measures made in different colors. But the spot darkness is evidently of a different character, the thermal intensity being extraordinarily high, and it is certainly not possible to explain it by assuming a greater thickness of the *same* absorbing material.

For supposing we reject Langley's and Frost's measures of abnormal spots giving a higher thermal intensity than the photosphere and consider Wilson's average result, namely .75 at .95 from the Sun's center, to be an overestimate. If a spot near the limb gave only .66 of the thermal effect of the surrounding photosphere, then, assuming the darkening of spot and limb to be only a question of degree, this would imply in the spot a 34 per cent. absorbing layer added to that which gives the general

absorption. But a layer which absorbs 34 per cent. of general radiation (heat) will absorb 46 per cent of light[1] if it is of the same material which covers the photosphere, leaving .54 as the photometric value of the umbra compared with the adjacent photosphere, or about .25 compared with the center of the disk; values which are evidently quite inadmissible, for large spots near the limb often appear as dark as the sky, their intrinsic light being only a minute fraction of that of the surrounding region.

A possible clue as to spot darkness has occurred to the writer which does not necessitate absorption and still does not violate the ordinary laws of heat exchange. The temperature gradient in the Sun is not known, but it is believed that the temperature near the surface must increase very rapidly with the depth. According to Oppolzer this increase must be at least 6000° C. for each second of arc (see *Astronomy and Astrophysics*, Oct. 1893, p. 739). A few thousand miles below the photosphere therefore the temperature must enormously transcend that of the Sun's visible surface. Is it possible that the radiation from this inconceivably hot interior region takes place in wave frequencies of a higher order altogether than that of the photosphere?— the visible radiations being relatively feeble.

This assumes that in a radiating body at high temperature the intensity of the longest waves tends to diminish with increase of temperature. That is, as the radiations of maximum energy move up the spectrum with increasing temperature, the actual as well as relative intensity in the lower region of the spectrum must be supposed to diminish.

In a general way the shifting of the maximum intensity towards the violet with increase of temperature may be said to be confirmed by star spectra. It is well known that the photographic magnitudes of many stars do not correspond with the visual magnitudes. Thus the first type stars are photographi-

[1] Compare the tables of absorption given by Wilson and Rambaut: "The Absorption of Heat in the Solar Atmosphere" (*Proc. Royal Irish Acad.*, 3d series, Vol. II, No. 2), and Young, *The Sun*, 4th ed. p. 247.

cally brighter than solar stars of the same visual magnitude, that is the blue and violet in the spectrum of the hotter stars is relatively brighter than the yellow and red.

Whether the red rays are really less bright in the Sirian stars than would be the case if the temperature were reduced to that of the solar stars, it is not possible to say. Langley has found however, that very far down in the normal solar spectrum the intensity is very much less than might have been expected. He found it easier, in fact, to detect these long waves in the spectrum emitted by a copper vessel filled with boiling water, and even in the rays of the Moon when its surface has become slightly warmed by the Sun.[1]

It would seem not impossible therefore that in the radiation of a Sun-spot this relatively feeble part of the spectrum has crept up into the shorter visible wave-lengths, following the rays of greatest energy which have traveled far up into the ultra-violet. It is true that if this be the real explanation of spot darkness the total radiation of the umbra should greatly exceed that of the photosphere, whereas according to Wilson's measures it is never even equal to it. It is probable, however, that the bulk of the energy would be absorbed by the Earth's atmosphere, which is a far more efficient screen for the ultra-violet rays than for visible light. It would seem too, that some of the energy does not assume the form of heat on reaching the Earth, but is effective in producing those magnetic disturbances which are characteristic of large umbræ.

But as the writer has already pointed out, a little further research into the character of the spot band in the invisible reaches of the spectrum would doubtless throw much light on the question, even if it did not at once demolish the above somewhat speculative theory.

[1] S. P. LANGLEY, "The Solar and Lunar Spectrum" *Mem. Nat. Acad. Sci.*, Vol. IV, Part. I.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

II. THE BUILDING AND MINOR INSTRUMENTS.

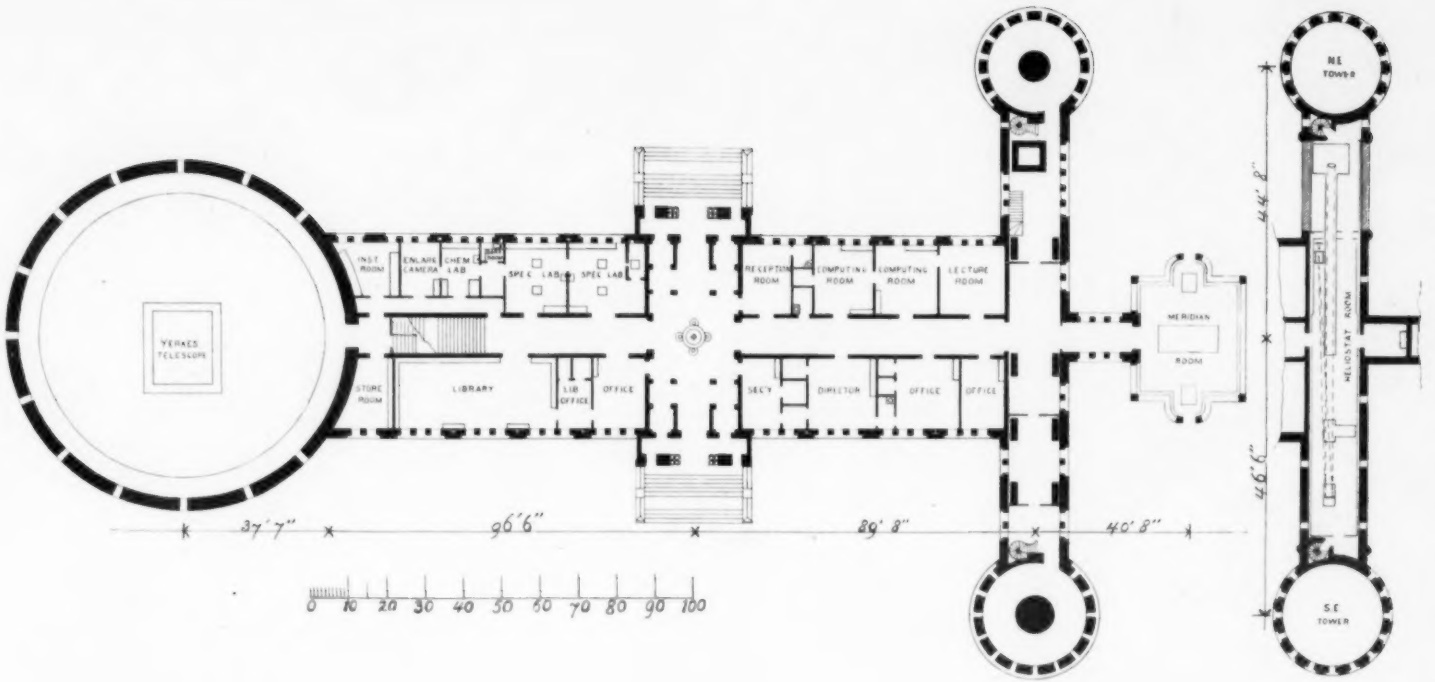
By GEORGE E. HALE.

REFERENCE has already been made to the plan of work prepared for the Yerkes Observatory in 1892.[1] This choice of subjects for investigation followed naturally and simply from a consideration of the special advantages of the forty-inch telescope, the principal instrument of the Observatory. These advantages are: (1) high resolving power, adapting it for observations of double stars, and minute detail in the surface markings of the Sun, Moon, planets, and satellites; (2) great light-gathering power, making possible spectroscopic studies of faint stars, and micrometric and photometric observations of faint satellites, stars, and nebulæ, variable stars at times of minimum brightness, and comets long after perihelion passage; (3) great focal length, giving large images in the principal focal plane of the Sun, planets, and planetary nebulæ, admirably suited for spectroscopic work. It was decided that in order to derive the greatest possible return from the use of the great telescope, full provision should be made for carrying on investigations in these various fields of work. The greater part of these observations being of an astrophysical character, it became necessary to provide the Observatory with laboratories equipped for the numerous researches of a physical nature required for their interpretation.

There was another reason, no less important than those already mentioned, for emphasizing the astrophysical side of the Observatory's work. Although important astrophysical observatories existed at that time in France and Germany, and provision had been made for astrophysical work in the national observatories of England and Russia, there was no observatory in North

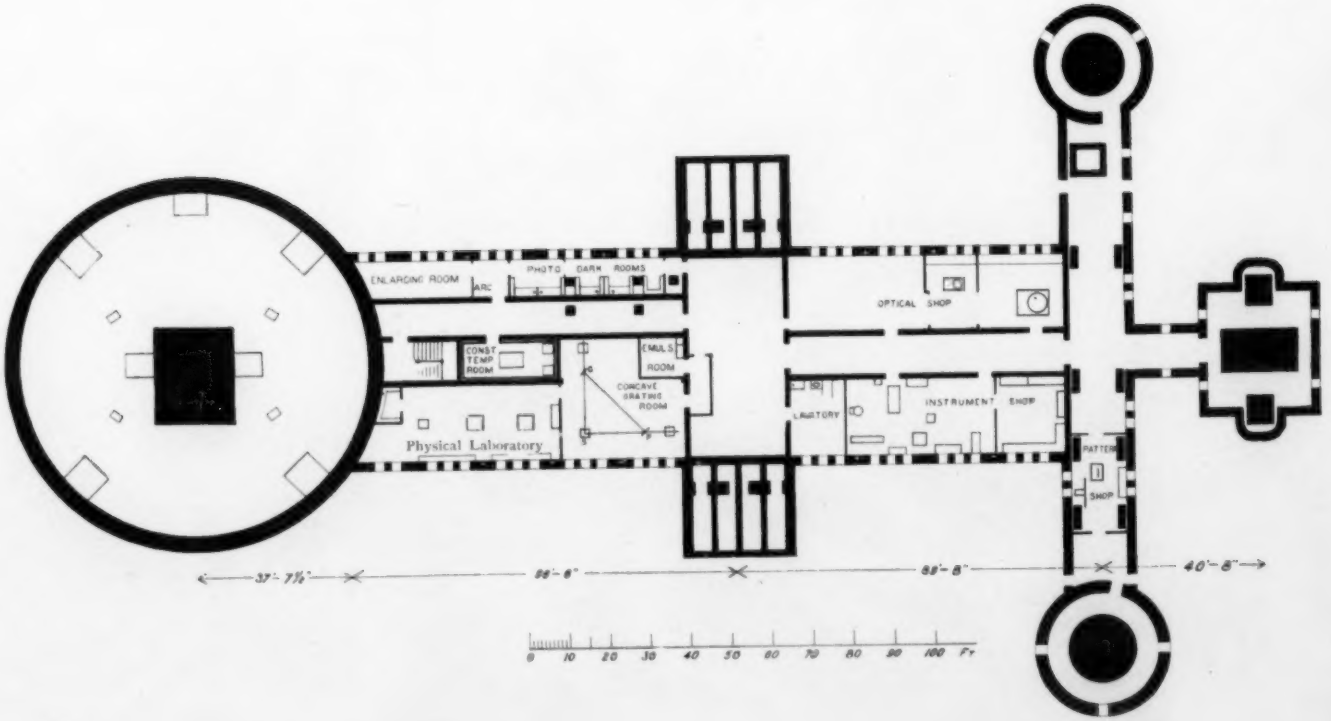
[1] See a previous article in this series, *Ap. J.* **5**, 164, March 1897.

PLATE IX.



MAIN FLOOR OF THE YERKES OBSERVATORY.

PLATE X.



GROUND FLOOR OF THE YERKES OBSERVATORY.

America which was completely equipped for such investigations. The Allegheny Observatory probably represented more nearly than any other such a union of astronomy and physics as an astrophysical observatory implies; but in the absence of a large equipment and staff, the successive Directors, Professors Langley and Keeler, had necessarily confined their very successful work to investigations which could be carried on without the aid of large instruments. At the Harvard and Lick Observatories, where so many important researches had been made on the astronomical side of the subject, laboratories provided with the means necessary for attacking the more distinctly physical problems involved were lacking. On the other hand, such spectroscopic laboratories as that of Johns Hopkins University were unable, for lack of instrumental means, to carry their fundamentally important researches beyond the artificial boundaries of physics into the realm of astronomy. At the Smithsonian Institution Professor Langley had mounted in temporary quarters the apparatus used in his important bolometric researches, but Congress had not seen fit to provide funds for establishing on a proper scale a national astrophysical observatory.[1] In short, in spite of the wealth of observatories and laboratories in the United States, and the numerous contributions to astrophysics of Rutherford, Draper, Young, Pickering, Langley, Rowland, Keeler, Michelson, Hastings, and many others, there was yet to be founded an observatory which should adequately represent both the astronomical and physical sides of astrophysical work, at the same time providing the necessary facilities for research work in astronomy of position. It was therefore felt that an attempt should be made to meet this need, as adequately as circumstances would permit.

For instrumental equipment there was in the first place the forty-inch telescope, for which Mr. Yerkes had ordered a filar micrometer from Warner & Swasey, and a stellar spectrograph from Brashear; and in addition to this the instruments of the

[1] It is greatly to be hoped that Professor Langley's plans for creating such an observatory will soon be realized.

Kenwood Observatory, consisting of a twelve-inch refractor, fitted with both visual and photographic objectives, a spectroheliograph, and other attachments; a four-inch concave grating of ten feet focus, with complete mounting; and a collection of minor apparatus, including clocks, spectroscopes, gratings, prisms, etc. It was decided that there should be added as soon as possible a sixteen-inch refractor for micrometric work; a large heliostat with various accessory apparatus; a transit instrument, and subsequently a meridian circle; a large spectroheliograph and a solar spectroscope for the forty-inch equatorial; and a collection of instruments for laboratory work, including special spectroscopes, refractometers or "wave-comparers," and bolometric apparatus.

An attempt was then made to design a building which should meet as many as possible of the conditions imposed by the observations to be made with these various instruments.

Work on the plans was not begun until nearly all of the important observatories and spectroscopic laboratories of the United States and Europe had been visited and studied. Ideas were freely borrowed from these institutions, particularly from the Lick Observatory and the Astrophysical Observatory at Potsdam. The preliminary plans were completed at Berlin in February 1894, and despatched to the University architect, Mr Henry Ives Cobb of Chicago, who followed out the details with great care and success, sacrificing none of the scientific requirements for architectural effect.[1] Full credit for the architectural design is due to Mr. Cobb, as the writer is responsible only for the general form of the building, and for the interior arrangement only so far as this is determined by the requirements of the Observatory's work. Owing to the fact that The University did not come into possession of the property at Lake Geneva until late in the autumn of 1894, the work of construction could not be undertaken before the following spring. The interven

[1] This may not prove to be the case in the meridian room, which had been planned as a light iron skeleton, with double sheet-iron walls and intervening air space. The addition of the terra-cotta cornice will not tend to improve the conditions required for the best work.

PLATE XII.

CENTRAL ROTUNDA OF THE YERKES OBSERVATORY.

ing time was spent in perfecting the plans, which were much improved as a result of further study and the adoption of important suggestions kindly offered by various men of science, to whom the thanks of the Observatory are due. They were finally completed in February 1895, and the first excavations for the building were made in April of the same year. The work of construction was carried on with various interruptions through the two succeeding years, and is now (March 1897) nearly completed. The Observatory has been occupied by the present members of the staff since October 1896.

As will be seen from an inspection of the plans (Plates IX and X) the form of the building is that of a Latin cross, with three towers and a meridian room at the extremities. This form suggested itself as one permitting the various domes to be well separated, at the same time providing sufficient space for the laboratories and other rooms between the towers. The long axis of the building lies on an east and west line, and is 326 feet in length. The large tower at the western extremity, which contains the forty-inch telescope, is ninety-two feet in diameter. This tower, together with the large telescope, dome and rising-floor, will be described in a subsequent paper. For the present attention will be confined to the other parts of the Observatory.

An examination of the accompanying illustrations will show that Mr. Cobb has worked out the design in the Romanesque style, with somewhat Saracenic details recalling the Church and Monastery of Monreale. The north and south entrances (Plate XI), which lead into the central rotunda (Plate XII), are in all respects precisely similar. The building is constructed of brown Roman brick, with terra-cotta ornaments of the same color. That portion which lies between the three towers is two stories high, with an attic above. The small towers are carried up to a greater height, in order that the large dome may not obstruct too much of the western sky in observations with the small telescopes. Balconies are provided on all the towers, with doors at the cardinal points leading out from the observing rooms. The astron-

omer is thus enabled to command an unobstructed view of the sky at any time while observing.

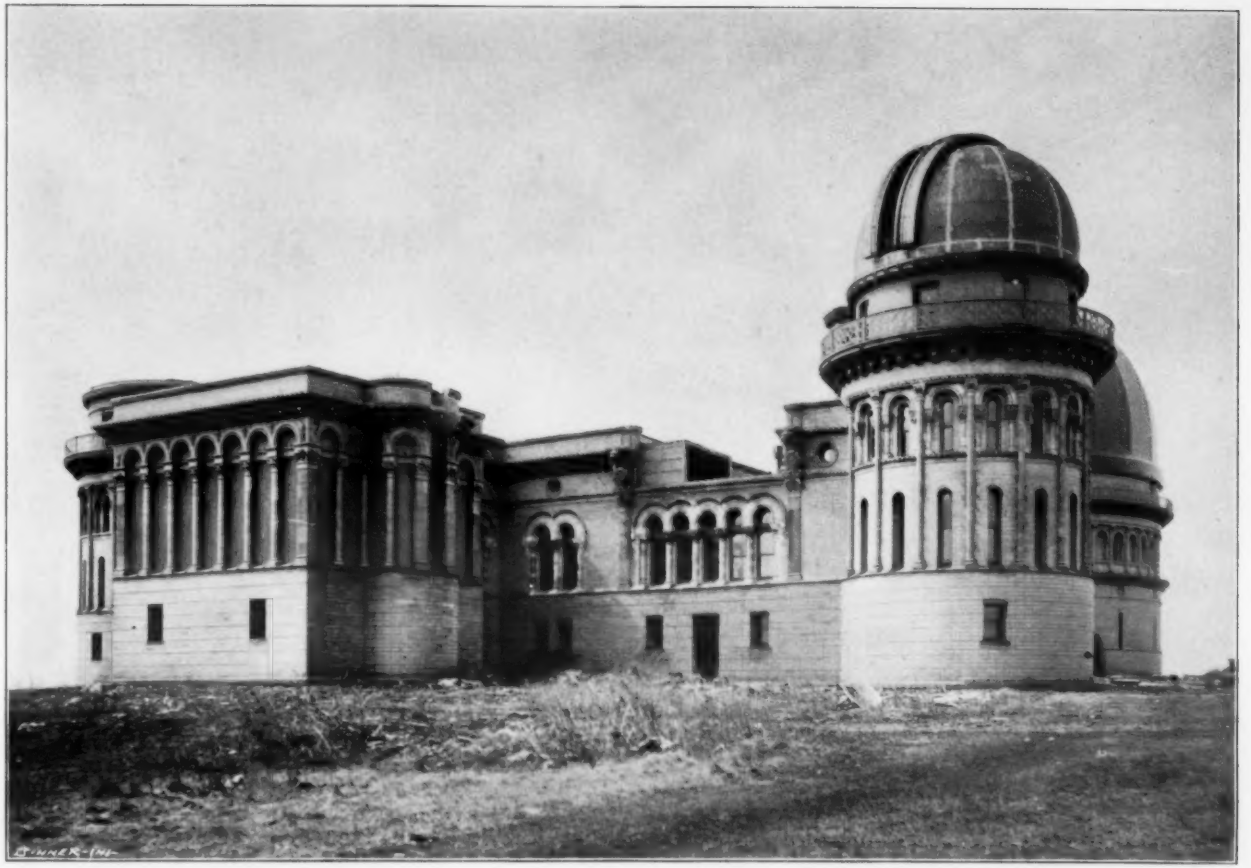
NORTHEAST TOWER.[1]

The northeast tower, thirty feet in diameter, is surmounted by the dome which was formerly a part of the Kenwood Observatory. This dome was built by Warner & Swasey in 1890. The running gear is on the familiar "live-ring" plan, the circular cast iron ring, from which the dome girders spring, resting on the central wheels in fourteen groups of three; the two outer wheels of each group roll on a circular iron track bolted to the stone coping which caps the brick wall of the tower. The groups of wheels are connected together with iron rods, which maintain them at constant positions in the ring. Lateral guide wheels prevent displacement in a horizontal plane. The dome is revolved by means of an endless wire rope, which passes around a ring of angle iron supported just inside of the upper track, and is brought down over guide wheels to a grooved wheel mounted in a recess cut in the south wall of the tower. This wheel is turned by means of an endless rope, hanging in the wall recess within easy reach from the floor of the observing room. The dome is covered with steel plates, bent to form and riveted to the light iron girders and to each other where they overlap. The observing slit, three feet wide, can be closed by means of a double shutter, the halves of which are moved on tracks at top and bottom by racks and pinions, controlled by a wire rope.

Under this dome is mounted the twelve-inch telescope which was formerly at the Kenwood Observatory in Chicago (Plate XIV). The solid brick pier which carries it is in form a frustum of a cone rising from a heavy concrete foundation. The mounting was constructed by Warner & Swasey in 1890, and served admirably for work with the large spectroheliograph of the Kenwood Observatory. It is unnecessary to more than briefly refer to it here. Two twelve-inch objectives by Brashear are provided.

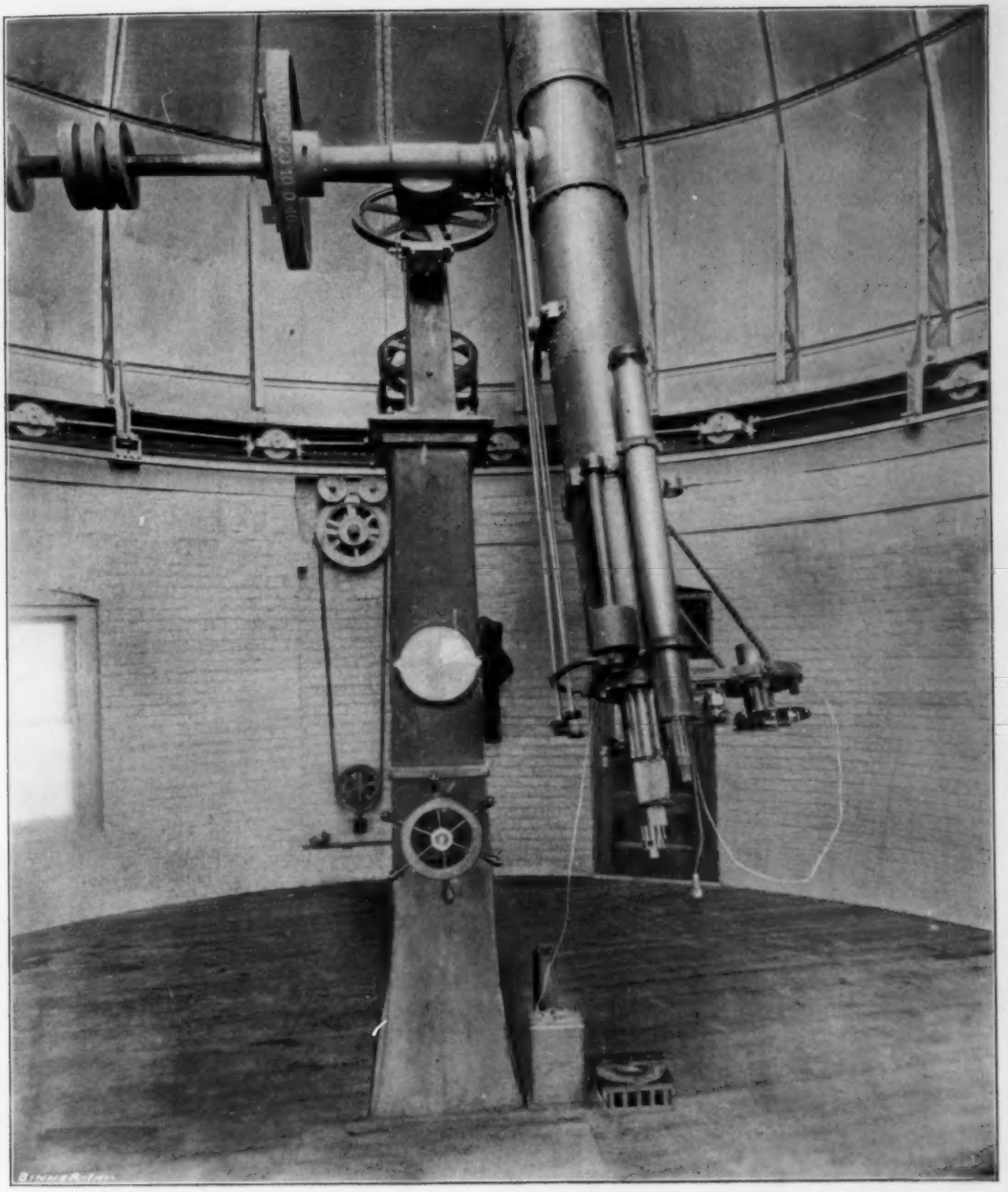
[1] This tower, together with the meridian room and heliostat shutter, are shown in Plate XIII. The small dome has not yet received its final coat of paint.

PLATE XIII.



NORTHEAST WING OF THE YERKES OBSERVATORY.

PLATE XIV.



TWELVE-INCH TELESCOPE OF THE YERKES OBSERVATORY.

NORTHEAST WING OF THE YERKES OBSERVATORY.

For observations with the micrometer only the visual objective is employed, in the usual position at the end of the tube. When it is desired to transform the instrument into a photoheliograph, the photographic objective, mounted in a short tube, is attached to a stout side bracket at the upper end of the steel tube of the telescope. A specially designed rotating shutter, driven by an electric motor, is then clamped to a corresponding bracket at the eye-end, which also carries an enlarging camera. With this arrangement, which will be described more in detail elsewhere, the solar image can be photographed in the focal plane of the objective, or, by the aid of a suitable amplifying lens, enlarged to any scale desired. Means are provided for attaching to the telescope the Kenwood spectroheliograph, which has lately been remodeled in the instrument shop; the stellar spectrograph of the forty-inch telescope; a ten-inch objective grating;[1] and several small grating, prism and direct-vision spectroscopes.

SOUTHEAST TOWER.

The southeast tower is intended for a sixteen-inch telescope, mounted under a dome thirty feet in diameter. This dome has not yet been erected.

MERIDIAN ROOM.[2]

This is constructed on the general plan of the meridian room of the Royal Observatory at Berlin, with double sheet-iron walls and intervening air space, provided with suitable means of ventilation. The room is twenty-eight feet long (exclusive of the projections containing the collimator piers), twenty-five feet wide and twenty feet high. The observing slit is three feet wide, and is covered with a counterbalanced shutter, the sections of which can be easily opened and closed by the aid of small windlasses. A massive brick pier upon a broad foundation of concrete has been built for a meridian circle, and collimator piers have also been provided. For some time to come a transit instrument

[1] See this JOURNAL, **4**, 75, 1896.

[2] See Plate XIII.

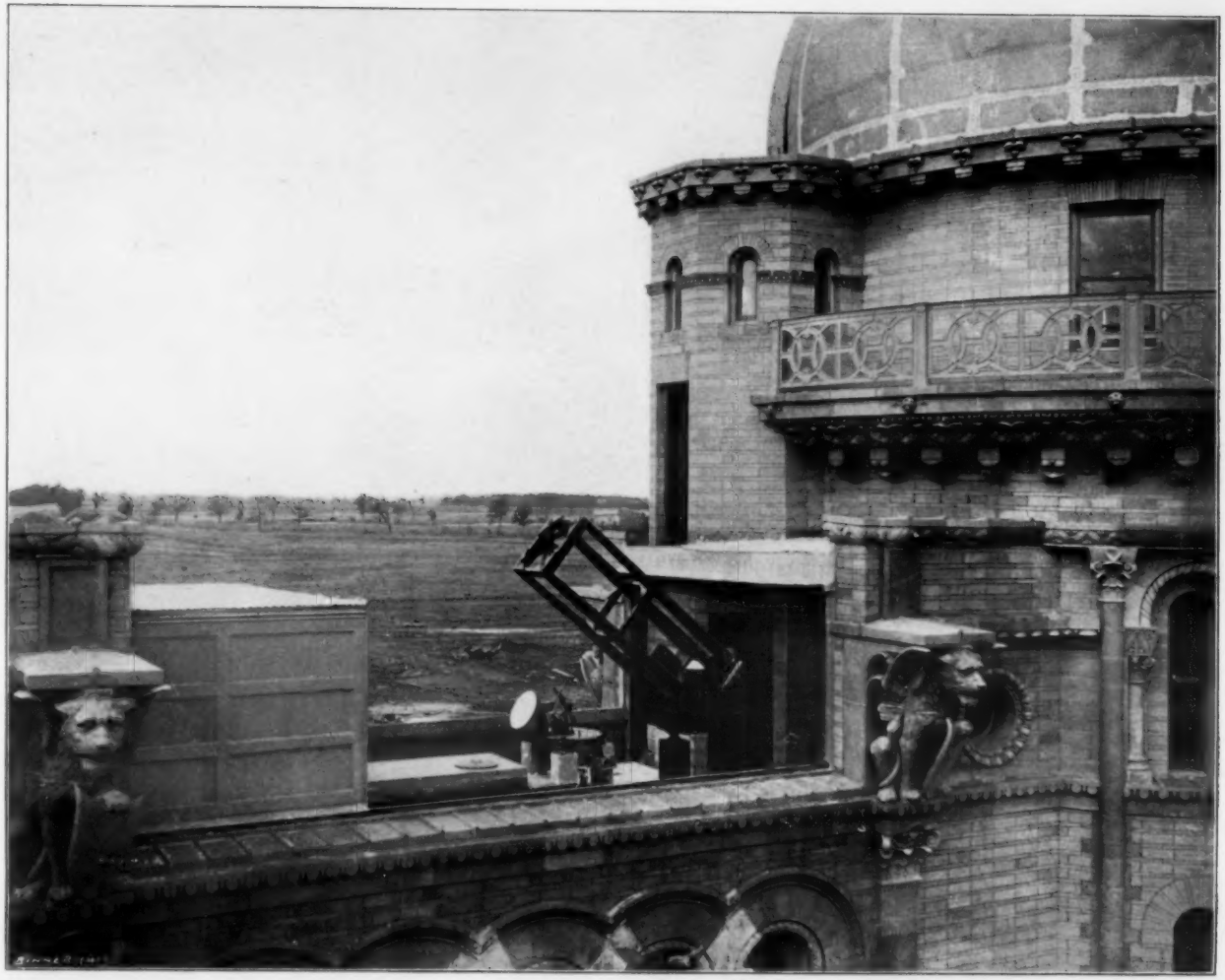
will be used in this room, on a smaller brick pier built in the center of the large pier; but it is intended that this shall subsequently give place to a large meridian circle. The architect has relieved the bareness of the outer sheet-iron walls by the use of a row of columns supporting a rich terra-cotta cornice.

HELIOSTAT ROOM.

An important feature of the Observatory is the heliostat room, which occupies the whole of that portion of the attic floor which lies between the two small towers, a space 104 feet long and twelve feet wide. Twenty-four feet from its northern extremity it is crossed by a double partition, in which are suitable openings for admitting the sunlight. The heliostat (Plate XV) stands on a large brick pier, which rises from the ground at the north end of the room. The iron roof which ordinarily covers it can be pushed away to the south, as it is mounted on wheels rolling on steel rails. It is easily moved by means of a windlass. When the roof is fully withdrawn, the heliostat mirror can receive the rays of the Sun when at its greatest southern declination. That part of the heliostat room which lies south of the double partition is shown in Plate XVI.[1] The walls and ceiling of this laboratory are of sheet-iron, separated from the brick walls and tile roof by an air space. In winter the laboratory is heated by indirect radiation from steam coils in the corners of the unfinished attic rooms. Arrangements are made by which the heated air can be thoroughly dried over unslaked lime as it enters the room, thus greatly facilitating work with rock salt prisms or lenses. The heliostat room contains four piers, the outlines of which are indicated in the plan. Each of these is supported by two separate piers, standing on opposite sides of the hall below, and bound together at the level of the first and second floors with heavy I-beams. The two northern piers are connected to each other and to the

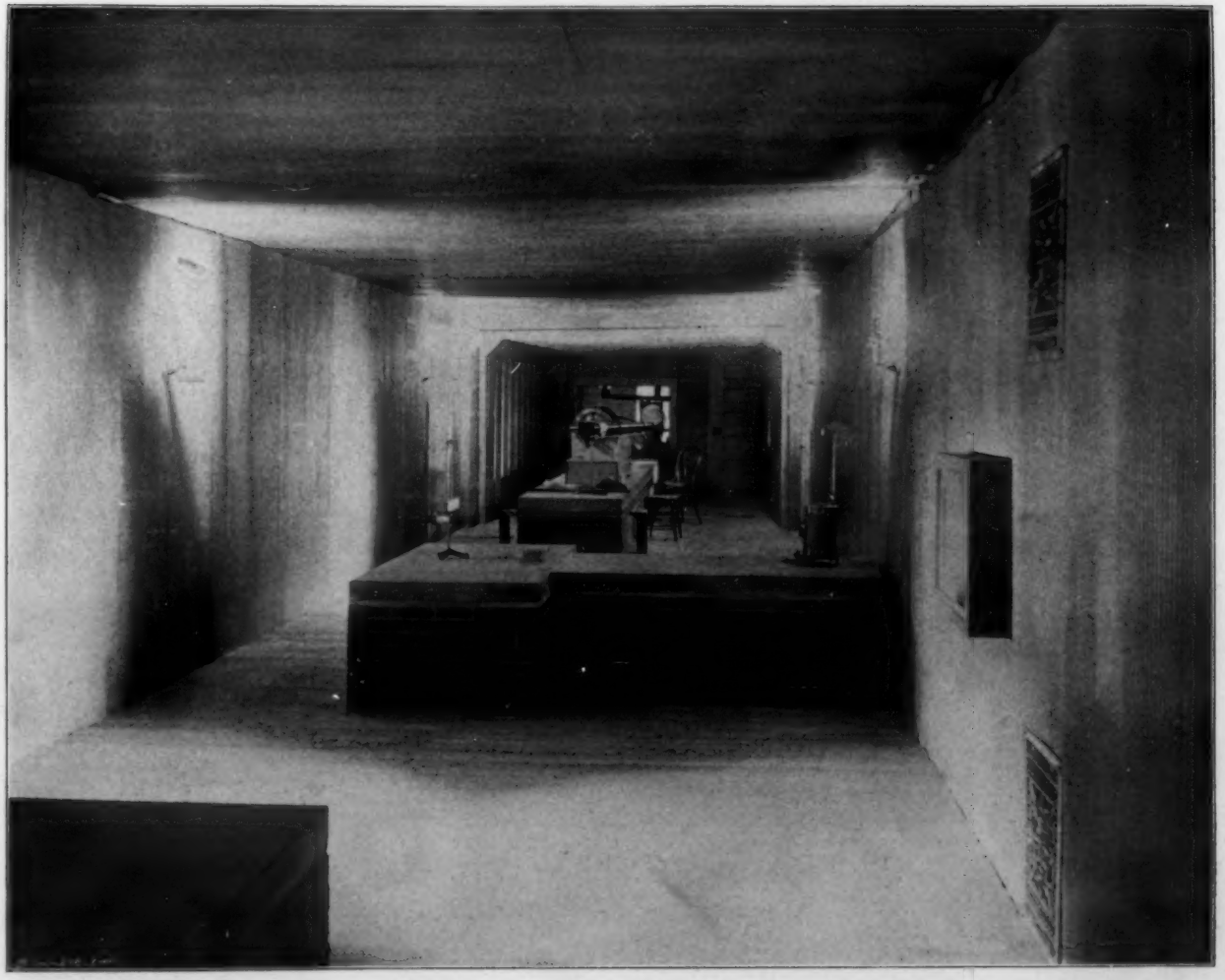
[1] When the photograph reproduced in this plate was taken the apparatus described below had not been set up in the heliostat room. The instrument shown is a large spectroscope, temporarily mounted for the purpose of testing Abney's method of photographing the Sun in monochromatic light.

PLATE XV.



HELIOSTAT ROOM OF THE YERKES OBSERVATORY (EXTERIOR).

PLATE XVI.



HELIOSTAT ROOM OF THE YERKES OBSERVATORY (INTERIOR).

heliostat pier with three 15-inch I-beams, which form the essential part of the long pier shown in the plan. All of the piers have smooth slate tops.

The instruments outlined in the plan of the heliostat room are those used by the writer in his attempts to map the solar corona without an eclipse by the aid of a bolometer. Sunlight is reflected from the heliostat mirror to a silvered concave mirror of twenty-four inches' aperture and sixty-one feet focal length, made for these experiments by Mr. G. W. Ritchey, optician of the Observatory. The mirror forms an image of the Sun nearly seven inches in diameter in a large cast-iron drum. The sunlight passes through the drum without touching it, and falls upon an amplifier, which forms an enlarged image on a screen. The bolometer is mounted in a radial slot in the drum. The inner member of the pair can be set at any desired distance from the Sun's limb and, by rotating the drum, at any position angle. The outer member is supported at right angles to the inner radial member, and its distance from the limb is constant. An assistant maintains the solar image at a fixed position on the screen by means of the slow motions of the heliostat, and rotates the drum at a signal from the observer, who watches the scale of an extremely sensitive reflecting galvanometer with a telescope. It is desired to determine whether any differences in the heat radiation of the corona can be detected at different position angles. The heliostat at present employed has been loaned to the Observatory by Professor Keeler until the one which is being constructed in our instrument shop is completed. Its mirror has an aperture of seventeen inches. The new heliostat is to have a mirror of twenty-four inches aperture, which is now being figured in our optical laboratory. The new instrument is designed to combine the functions of heliostat and coelostat, in the latter case a second fixed mirror being used with it.

A galvanometer room, provided with a heavy slate shelf to support the instrument, immediately adjoins the heliostat room on the east. The large attic rooms to the west are so arranged that they can also be used in conjunction with the heliostat room.

The entire distance (175 feet) between the heliostat room and the wall of the great tower is available for use with apparatus containing mirrors or lenses of great focal length, etc.

SPECTROSCOPIC LABORATORIES.

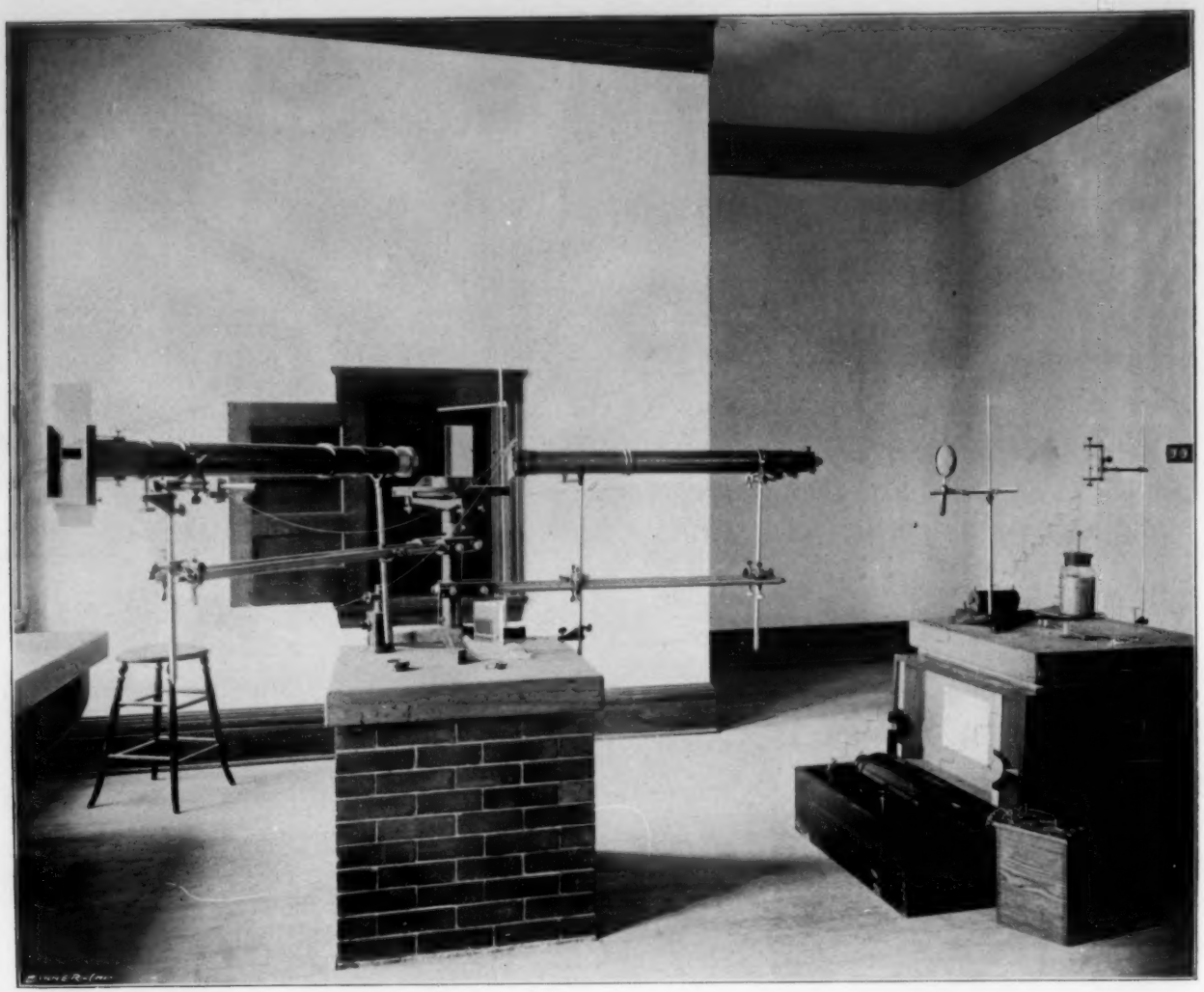
The main floor of the building is divided into offices, computing rooms, spectroscopic laboratories, chemical laboratory, instrument rooms, developing room, lecture room, library and reception room. The purpose of each room is indicated on the plan.

The spectroscopic laboratories (Plate XVII) are provided with solid brick piers on concrete foundations, which are arranged with reference to each other and to the doors and windows so that the instruments mounted upon them can be used together, or with heliostats or other apparatus mounted in the open air. In the corner of one of these laboratories is a galvanometer room containing a brick pier and heavy slate wall shelf, specially arranged for bolometric work. Two extremely sensitive reflecting galvanometers are provided. Both of the laboratories have slate shelves, four inches thick, supported by heavy slate brackets built into the outer brick wall. Sinks and running water are also provided, and the windows are fitted with rolling wood shutters, which completely exclude the light when closed. The collection of physical apparatus includes spectroscopes of various kinds, bolometers, galvanometers, interferential refractometers or "wave comparers," induction coils, special electrode holders for spectroscopic work, a Wheatstone bridge, resistance coils, and numerous prisms, gratings, achromatic objectives and mirrors of glass and speculum metal. A small photographic dark room immediately adjoining the spectroscopic laboratories is used in conjunction with them.

CHEMICAL LABORATORY.

The chemical laboratory is fitted with slate shelf, rolling window shutters, sink and running water, and a glass-covered "hood" with suitable ventilation, in which experiments with

PLATE XVII.



SPECTROSCOPIC LABORATORY OF THE YERKES OBSERVATORY.

noxious gases can be performed. It is equipped with a good assortment of chemicals, chemical glassware, balances, appliances for glass blowing, etc.

ENLARGING CAMERA.

In the room adjoining the chemical laboratory there is a large camera, specially designed for copying photographs on any desired scale of enlargement.

INSTRUMENT AND STOREROOMS.

The cases in the instrument room contain a varied collection of instruments and parts which are not needed for immediate use. The room opposite it is intended for general storage purposes; all the wood patterns made in the pattern shop are kept here after being returned from the foundry.

COMPUTING ROOMS.

The two computing rooms are fitted with heavy slate shelves to carry the measuring instruments, one of which, a Zeiss comparator, is already in use. They also contain cases designed for the preservation of the numerous photographic negatives obtained in the course of the Observatory's work. The Kenwood Observatory collection of over 3500 negatives, mainly of solar phenomena, is preserved here for convenient reference.

LIBRARY.

The library is a room 18 by 42 feet, all the available wall space of which is covered with oak bookcases, having shelves above and cupboards below. The librarian's office, provided with an iron vault for the storage of valuable papers, immediately adjoins it. The collection of books is at present far from complete, but important additions are constantly being made. The thanks of the Observatory are due for the valuable contributions which have been received from individuals and scientific institutions in all parts of the world. Some fifty different scientific periodicals are regularly received by the library. On

account of its isolated position, removed from the reference libraries of Chicago, it is of the highest importance that the collection of books be made as large and complete as possible. It goes without saying that all contributions of scientific publications have been exceedingly welcome.

The Observatory possesses a large and increasing collection of photographs, including those exhibited by the Royal Astronomical Society at the Columbian Exposition, and afterwards presented to the Observatory; a complete set of glass positives from Professor Barnard's portrait-lens photographs of the Milky Way, comets and nebulæ; and the Kenwood Observatory collection.

RECEPTION ROOM, OFFICES AND LECTURE ROOM.

The reception room for visitors opens out of the central rotunda.

Several rooms on the main floor are used as offices by members of the staff, as indicated in the plan (Plate X).

At one end of the long corrider is a lecture room, containing a large blackboard.

CONCAVE GRATING ROOM.

The floor below is reached by stairs at both ends of the building. The eastern half of this lower story is devoted to the optical laboratory and the instrument and pattern shops, which, with the power house, will be described in another article. The western half contains the concave grating room, physical laboratory, constant temperature room, emulsion room, enlarging room, and photographic dark rooms. The concave grating room is specially designed to contain a concave grating of twenty-one feet radius, mounted in the ordinary manner. The instruments at present used are a four-inch concave grating of ten feet focus, and a smaller one of six feet focus, from the Kenwood Observatory collection. The three brick piers, with slate tops, which carry the mounting, are shown in the plan (Plate XI). The slit is at *S*, the grating at *G*, and the plate-

holder or eyepiece at *P*. Sunlight is reflected into the room from the mirror of a heliostat placed outside the window, a lens being interposed to form an image of the Sun on the slit. An image of an electric arc or other light source may also be formed on the slit, either by placing the light in the direction from which the sunlight comes, or to one side, a reflecting prism being employed in the latter case. A window has been cut in the partition which separates the concave grating room from the adjoining physical laboratory, and the centers of the piers in this latter room are in line with the rail on which the plate carriage moves. Thus any desired apparatus can be used in conjunction with the concave grating. Both rooms have rolling wood shutters, which effectually exclude the light. The physical laboratory is also provided with heavy slate shelves and an instrument case. The piers in this room have been found to be extremely steady, the most sensitive galvanometer showing no signs of vibration due to the machinery in the instrument shop. A variety of minor apparatus, consisting of a large Apps induction coil, mercury pump, oxy-hydrogen burners, arc lamp, special electrode holders for spark spectra, Geissler tubes, etc., from the Kenwood Observatory collection, is available for use with the concave grating, or in the other laboratories. The concave grating room is reached from the central hall through a passageway having both outer and inner doors. Thus the room may be entered at any time during a long exposure without danger of admitting light and fogging the plate.

EMULSION ROOM.

In one corner of the concave grating room is the "emulsion room," fitted with sink and running water for photographic purposes. The walls and ceiling are painted black, and can be sponged perfectly free from dust when photographic preparations requiring very careful treatment are to be made. This room can also be entered from the central hall without danger of admitting light.

PHOTOGRAPHIC DARK ROOM.

The large photographic dark room is on the north side of the building, opening into the central hall through a double door. It is divided into three stalls, two for developing and one without sink or water for use in changing plates. Each stall is supplied with numerous shelves, and each has a ventilated recess in the wall fitted with a swinging door glazed with red glass, designed to contain the electric or oil lamp used for illumination. Immediately adjoining the developing room is a room for fixing and washing plates. Two sinks are provided, one to contain "hypo" tanks for plates of various sizes, the other for the washing tanks. The outside windows of this room are glazed with red glass, and admit much more light than would be safe in a developing room, but not too much to affect the plates before and during their immersion in the hyposulphite bath.

ENLARGING ROOM.

The small room next to this contains a photo-engraver's arc-lamp, for enlarging and copying photographs by electric light. A pair of large condensers are fitted into an opening in the partition, and within there is a frame for supporting the negative. Beyond this is the enlarging lens, which projects the image upon a screen mounted on rollers, which can be set at any desired distance (up to twenty-four feet). All of these rooms are provided with rolling wood shutters, which can be instantly opened or closed. The walls and ceilings are painted dark red. The developing and washing rooms have cement floors.

CONSTANT TEMPERATURE ROOM.

On the opposite side of the long hall is the constant temperature room, which has double walls with intervening air space and double doors. This room contains two clock piers, and a brick pier with large slate top for experimental work which must be carried on under conditions of constant temperature. The only astronomical clock yet in place is a fine Howard clock from the Kenwood Observatory.

All of the rooms of the Observatory are connected with boxes running along the ceiling of the lower story, through which electric wires can be drawn. The building is lighted throughout by incandescent electric lamps, and heated by steam. A system of telephones places the Director's office in communication with the three domes and the power house. But little wood was used in constructing the Observatory, the walls being of brick and terra-cotta on concrete foundations, the partitions of hollow tile, and the floors and roof of tile supported by steel I-beams. The floor of the long hall in the main story is of marble mosaic, and the walls are wainscoted with marble. The offices and laboratories have maple floors, and oak is used throughout the building for the doors and other wood finish.

PORTRAIT LENS AND COMET SEEKER.

A circular building ten feet in diameter, surmounted by a light steel dome having a very broad slit, has been erected on the Observatory grounds about 300 feet southwest of the great tower. This will contain an equatorially mounted portrait lens for photographing comets, the Milky Way, nebulæ, etc. A comet seeker will be established at no great distance from this dome.

REFLECTING TELESCOPES.

The Observatory will have the use of two large silvered glass reflecting telescopes. One of these, of twenty-four inches aperture and eight feet focal length, which was made by Mr. Ritchey for photographic work, is already employed for visual observations, on a temporary mounting in the heliostat room. The sixty-inch mirror of the other instrument, which is to be mounted as an *equatorial coudé* for astrophysical investigations, will soon be figured in the optical laboratory.

YERKES OBSERVATORY,
March 1897.

(*To be continued.*)

THERMAL MEASUREMENTS WITH THE BOLOMETER BY THE ZERO METHOD.

By F. L. O. WADSWORTH.[1]

IN the May number of the *Annales de Chimie et de Physique*,[2] in an article entitled "Sur le Bolometer," M. Crova describes what may perhaps be termed a zero method of using the bolometer, for which he claims a number of advantages. The arrangement which he proposes is only a modification of the well-known form of slide wire bridge which is now so universally used in the exact measurement and comparison of standard resistance coils, and the credit for any novelty which there may be in its application to the purpose for which he designs it belongs, I think, to Dr. Hallock, my predecessor in the Observatory, who first used it in the winter or early spring of 1892, over a year before the publication of M. Crova's paper.

When I was placed in charge of the work at the Observatory in October of the same year, I modified the existing arrangement, with a view to securing a more sensitive and reliable action, by substituting for the single balancing wire of copper two much larger wires of platinoid, which were stretched side by side about 1^{cm} apart, as shown at $a\,b$, $a'b'$, Fig. 1. The inner one was connected to the terminals of the bridge ab; the other one to one of the battery terminals, and a sliding clamp c used to connect the two. All movable wires were thus avoided and a smoother motion and better contact secured for the balancing

[1] Then Senior Assistant (in charge) of the Astrophysical Observatory, Washington, D. C.

[2] The main part of this paper was written, as may be seen by the appended date, over three years ago, or only a few months after M. Crova's article appeared. On account of pressure of other work it was laid aside and forgotten, until in looking over my papers a few days ago, I came across it. Although it is now considerably out of date as a reply to M. Crova's article I have been requested to publish it as it stands, although I hope before long to treat the whole subject of bolometric work in a more complete and satisfactory manner.

clamp. The wires were about 2^{mm} in diameter, and the change of resistance per millimeter of length was therefore

$$R = s\frac{l}{\pi r^2} = \frac{0.33 \times 10^{-5}}{0.0314} = \text{only } 0.0001 \text{ ohm.}$$

I soon found, however, that even this was far too large a rate of change for exact measurements, for with the new galvanometer

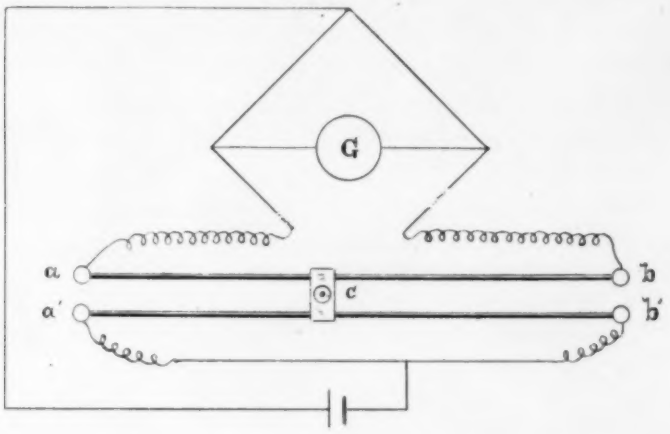


Fig. 1

which had in the meantime been constructed for the work,[1] the bridge system was so delicate that a movement of less than $0^{mm}.1$ caused a galvanometer deflection of more than a hundred divisions on the scale, and since the deflection could be read to a tenth of a division, it was at once evident that with this arrangement the accuracy of the zero method, even supposing that the position of the slider could be determined to $0^{mm}.01$, would only be about $\frac{1}{100}$ as great as the direct reading of deflections. In order to attain the same degree of accuracy, a balancing wire would have to be used having a cross section at least one hundred and probably one thousand times as great (since movements smaller than $\frac{1}{10}^{mm}$ can hardly be relied upon with any form of sliding contact). This would

[1] A description of this instrument appeared in the *Phil. Mag.* for December 1894.

have meant a wire over 60^{mm} in diameter, which was of course quite out of the question as a practical arrangement. This form of balance was therefore discarded and the one shown in Fig. 2 was, after some study, adopted in its place. In this we have the same two platinoid wires, $a\,b$, $a'b'$; the terminals $a\,b$ being connected to the bridge terminals as before, and the terminals $a'b'$ of the second wire being now connected by means of flexible copper conductors of small resistance to two movable clamps m, n, on the first wire. A third clamp o connected to the battery terminal slides upon the wire $a'b'$ The theory of this arrangement (which is simply a modified form of shunt), is as follows:

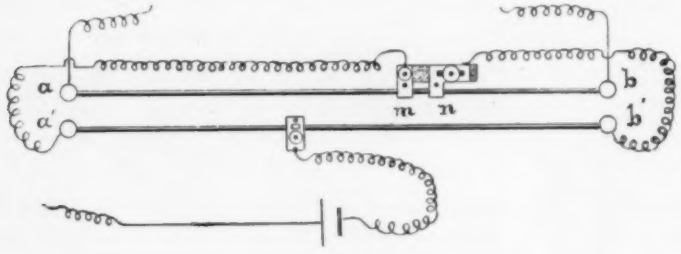


Fig. 2

Let x (Fig. 2) be the resistance of that portion of the wire $a\,b$ between the two clamps $m\,n$; p the resistance of that portion of the wire $a'b'$ from o to a'; q that of the wire from o to b', and R and R' the resistance from m to a and n to b respectively.

Then we have:

Total resistance o to a (left hand bridge terminal),

$$R_{oa} = R + \frac{1}{\frac{1}{p} + \frac{1}{q+x}} = R + \frac{p\,(q+x)}{p+q+x},$$

and total resistance o to b (right hand bridge terminal),

$$R_{ob} = R' + \frac{q\,(p+x)}{p+q+x}.$$

But R and R' may be considered simply as forming parts of

the bridge arms P, Q; and hence, when the bridge is in balance, $P + R = Q + R'$, and, therefore,

$$R_{oa} - R_{ob} = \frac{(p - q)\,x}{p + q + x}.$$

Let y be the distance of the clamp o from the center of the wire, and let l be the whole length of the wire $a'\,b'$. Then, if r_o is the resistance per unit length,

$$r_o y = p - q \text{ and } r_o l = p + q,$$

$$\therefore R_{oa} - R_{ob} = r_o y \frac{x}{r_o l + x}.$$

In the previous arrangement the change in resistance between the two arms of the bridge produced by moving the balancing clamp a distance y was simply $2\,r_o y$.

With the new arrangement the change in resistance for a given motion y has, therefore, been reduced in the ratio

$$\frac{x}{2\,(r_o l + x)}, \text{ or nearly } \frac{x}{2 r_o l},$$

if x is small as compared to l.

The second wire evidently plays the same part with respect to the first that the eyepiece of a telescope performs for the objective. The eyepiece magnifies the image formed by the objective in the ratio $\frac{f}{f'}$, while the wire $a'b'$ magnifies the motion of o in the ratio $2\frac{r_o l}{x} = 2\frac{l}{\overline{mn}}$, if the wires $a\,b$ and $a'b'$ have the same resistance per unit length. In the actual arrangement l was about 40^{cm}, and the distance $\overline{mn}$ was 1^{mm}. The magnification was, therefore, 800, or the system was equivalent to a single balancing wire having a cross section 800 times as great as that of the wires used. By making x still smaller, either by decreasing the distance $\overline{mn}$ or increasing the size of the wire $a\,b$, still greater magnification may, of course, be easily obtained, and the errors, due to inequalities in the size of the wire $a'b'$ and uncertainty as to the exact point of contact of the balancing clamp o with the latter, made as small as we choose. This arrangement, therefore, both on account of this greater sensitiveness and also on account of its greater compactness for

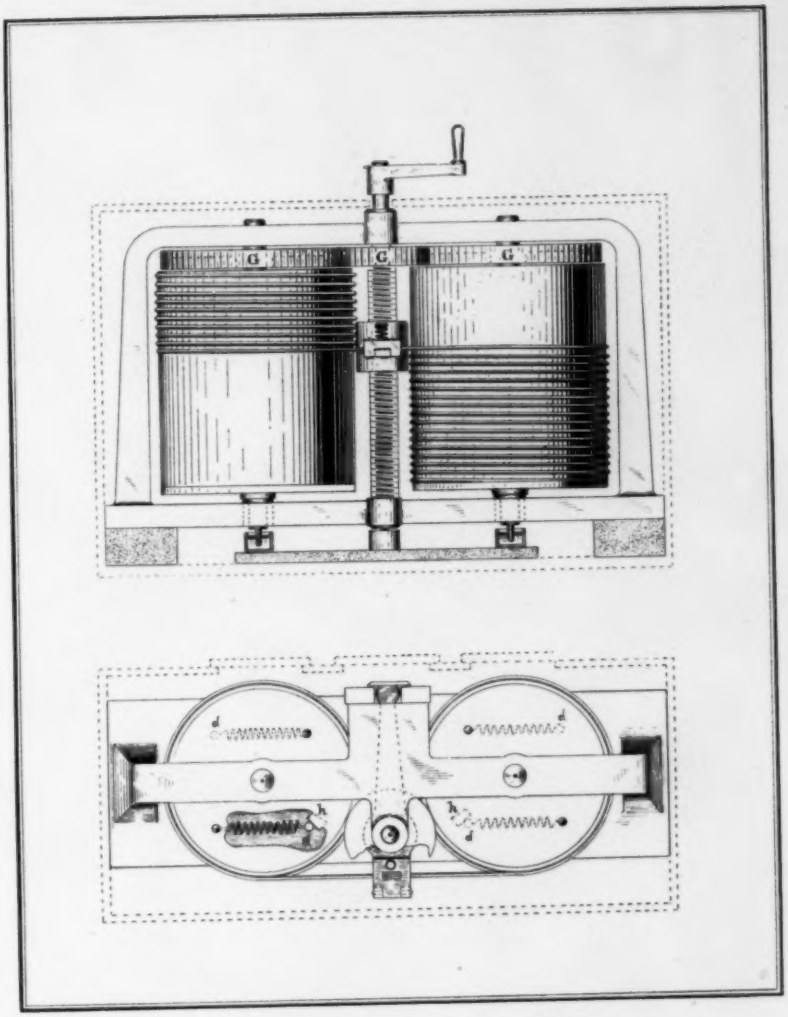
a given range of resistance, is far better adapted to accurate measurements by the zero method than the usual single-slide wire, and since, as we have just seen, the change of resistance is directly proportional to the linear movement of the balancing clamp or slider c, it is equally as convenient to use.

When the magnification is high the rate of variation of resistance along the wire $a'b'$ is, of course, low, and in order to obtain a considerable range the latter would have to be of considerable length.[1] In this case a very compact and convenient mounting for the second wire $a'b'$ is a modification of Thomson's drum rheostat which I have designed for this work and which is shown in plan and side elevation in Plate XVIII. The wire is wound, as shown in the plate, on two accurately turned ebonite cylinders,[2] which are geared together at one end by means of spur wheels G, G, G, so as to turn in the same direction with the same angular velocity. The ends of the wires are permanently attached to a heavy brass plate at the lower end of the cylinders and the sliding clamp, o, is carried on a copper screw s, which is driven by means of the intermediate gear G at a speed about twice that of the drums. The pitch of this screw is such that the clamp, o (which serves also as a guide for the wire, as it winds from one cylinder onto the other), moves a distance equal to about the diameter of the wire for every revolution of the screw. Continuous connection is made with the two plates with which the ends of the wire are connected by means of two attached copper wires which revolve in mercury cups, connected to the clamps m, n of the bridge system; and

[1] So far as a range of resistance is concerned, this is furnished by a movement of the two clamps m, n, either independently or together along the wire ab. But the accuracy of the determination of the change of resistance is in this case limited, just as in the case of the single-slide wire arrangement, by the accuracy of the determination of the position of the clamps m, n. It is well to have these movable in order to effect a preliminary adjustment of the bridge arms to approximate equality, and for this purpose it is convenient to have them so mounted on a single block of hard rubber (Fig. 2), that while they may be shifted slightly with respect to each other (in order to change the magnification if desired), they may usually be moved together as a unit along the wire ab.

[2] Brass covered with a thin sheet of ebonite would be better.

PLATE XVIII.



DRUM RHEOSTAT FOR BOLOMETRIC MEASUREMENTS.

connection is similarly established between the clamp *c* and the battery circuit through the copper screw *s*, the lower end of which revolves in a third mercury cup.[1]

The position of the slider with reference to one end or the center of the wire (or with reference to any intermediate point which may correspond to the initial zero of the bridge), is determined by means of a scale engraved on the guide in which the tail piece of the clamp, *o*, slides, and a graduated head on one of the drums; the former giving the whole number of turns and the latter the fractions of a turn of the drums; from which, when we know the diameter of the cylinders and the pitch of *s*, the length of wire wound from one to the other may be at once determined. In order to keep the wire under a constant tension and thus make the winding as smooth and regular as possible, the large gears are left loose on the shafts of the drums and are only connected with the latter by means of strong spiral springs, as shown in Plate XVIII.[2] In order to keep the wire at a constant temperature the whole arrangement may be immersed in a bath of oil, but it usually suffices to simply enclose it in a wooden box (as shown by the dotted lines), provided with a glass window through which the position of the slider may be read on the scale and graduated head. The minor details of construction may be easily understood from an inspection of the drawings themselves.

As regards the comparative advantages of the two methods (the deflection and the zero method) of measurement it is possible to institute only a very general comparison. The process of making thermal measurements with the bolometer is, it is true, only a process of making a series of measurements of

[1] To avoid any connection between the two ends of the wire the bearings in which the drum axles turn are mounted in rubber bushings and the gear on the screw is made of rawhide or vulcanite fiber.

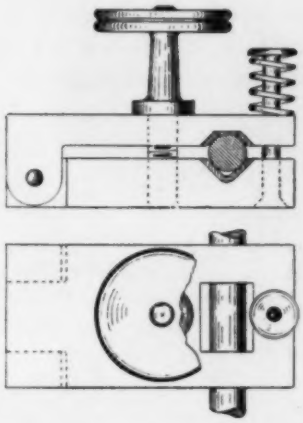
[2] A more accurate method of determining the position of the slider on the wire, which has recently suggested itself, is to make the latter in the form of a thick tape which is graduated on its upper surface. This would entirely avoid any errors due to irregularities in the winding or in the surface of the drum, or to changes in the tension of the wire.

resistance, and from that point of view alone the zero method would have the same advantages which attend its use in the accurate comparison of resistance coils by the slide wire bridge. The zero method has also a much wider range than the method of deflections, and if we wished to directly compare the radiation from two sources of energy, one of which is several thousand times as intense as the other, the former would be much more direct and perhaps also more accurate than the latter, which would necessarily involve the use of shunts.

On the other hand the method of deflections is much more expeditious and more readily admits of a continuous registration of the variations in the intensity of radiation falling on the bolometer strip, if these variations are not too large. It has also the advantage of involving no disturbance of contacts in any part of the bridge circuit, an advantage of so much importance when the bolometer is in its highest state of sensitiveness, that it practically excludes the employment of the zero method for accurate measurements of very feeble radiations. The reason for this is not at first apparent, for since the only sliding contact is at one of the battery terminals it would seem at first sight that any slight variation of resistance at that point would affect both arms of the bridge alike, and leave its balance undisturbed. But observation shows that any such variation (even when very small indeed) does affect the balance of the bridge very considerably, and the reason for this is that it causes a minute change of resistance and therefore a minute change of current in the battery circuit. In order to avoid this effect as far as possible many forms of sliding contact were tried. What is needed is something that can be easily slid along the wire, and at the same time can always be relied upon to maintain good contact. A sliding mercury contact is one of the first things that suggest themselves for this purpose, but none have been found that can be relied upon for any length of time. The best arrangement so far found is one similar to that shown in Fig. 3. It consists simply of two brass plates hinged together at the back and held together at the front

by a strong spiral spring. The wire lies in two V grooves lined with platinum, and cut away in the center in order to insure two perfectly definite points of contact at the ends. A screw is added to secure the clamp in place at any desired point on the wire. The clamp through which the wire passes in the case of the drum mounting already described is exactly similar in character.

Fig. 3



The effect of a small change of current in the bridge has not been considered, nor as far as I know even mentioned as a source of difficulty by those writers who have described most fully the manipulation of the bolometer, and I may therefore consider it, together with some other points of importance, more in detail in a subsequent paper.

Suffice it to say here, that in some of the earlier forms of bolometer (I have in mind particularly those designed and used by Mr. Langley in his thermal measurements in the infra-red spectrum at Allegheny, 1881–6),[1] a variation in the strength of the battery current of only one part in 1000 ($\frac{1}{10}$ of 1 per cent.), would produce a difference in the temperature of the two strips

[1] Described by Mr. Langley in the *Proceedings of the American Academy of Arts and Sciences*, **16**, 342, 1881.

of considerably over a tenth of a degree, or a difference a thousand times as great as that produced by the feeblest radiations which could be measured. This relatively enormous change in this case is due in large part to some radical errors in the design of these bolometers. With a properly designed and well constructed instrument this effect is reduced at least a hundred times, but it remains even then relatively large to the effects which are to be measured, and becomes of greater and greater importance as the delicacy of the whole system is increased. It alone is sufficient to account for nearly all the phenomena of bolometric "drift" which has been heretofore attributed to gradual changes in the temperature of the surroundings, or to changes in the amount of energy falling on the bolometer strip caused by changes in the atmospheric absorption.[1]

SMITHSONIAN ASTROPHYSICAL OBSERVATORY,
Washington, D. C., July 1893.

[1] That this latter explanation at least is very far from the true one is seen readily enough from the fact that the drift observed is often many times as great as could possibly be occasioned by the cause in question; many times greater, in fact, than that produced by changes in the radiation equal to the total amount falling on the bolometer strip.

Minor Contributions and Notes.

NOTE ON PROFESSOR CAMPBELL'S OBSERVATIONS OF NOVA AURIGAE.[1]

In *A. N.*, No. 3238, **135**, 386–390, I have given a long series of measures of the position of *Nova Aurigae* with reference to two comparison stars, *E* and *F*. These measures were made at Mt. Hamilton with the thirty-six-inch to detect parallax or motion, neither of which were shown to exist. In this paper I have the following note on the appearance of the *Nova*, which, from his remarks above, Professor Campbell seems to have overlooked.

"Much has been said of late in regard to the nebulosity of the *Nova*. Dr. Huggins, Dr. Vogel, and Mr. Newall think it is simply a telescopic effect.

"For my own part I am anxious to do all I can to settle the question, as I was instrumental in getting it started. I will therefore state all I have learned about this nebulosity. I have no theory whatever to defend, and simply wish the truth to be known, and if my observations can be of any service in getting at the true condition of this wonderful object I shall be satisfied.

"When I examined this star on August 19, 1892, it appeared to me to be densely nebulous, and since then it has not appreciably changed.

"The comparison star *F* is yellowish, while the *Nova* is bluish white. These two extremes of the spectrum make quite a difference in the focus for the two objects, as has been pointed out by Mr. Newall in his experience with the twenty-five-inch at Cambridge. This amounts to $\frac{3}{10}$ of an inch with the thirty-six-inch, and the *Nova* comes to a focus outside of that for *F*. When the *Nova* is in the best possible focus it is hazy and surrounded for $5''$ or $6''$ with a decided nebulosity. Now when *F* is in focus there is no such glow about it, nor is there about any of the other stars near.

"How much of this nebulosity is due to the peculiarity of the spectrum of the *Nova* I am not able to tell. But from my experience with nebulæ I would unhesitatingly say that the *Nova* is distinctly and

[1] See p. 240

unquestionably nebulous. It seems to me that Dr. Huggins' examination of this object with a large reflector—if he uses a high enough power—is the fairer test, as no peculiarity of refraction would enter into the formation of its image. To me the star is nebulous when in perfect focus both with the thirty-six-inch and the twelve-inch. As I have said, whether this is an effect of some peculiarity of its spectrum or not I am unable to tell.

"The following will cover the apparent phenomena: When the *Nova* is in perfect focus it is hazy or woolly, the image fading into a nebulous glow some 5″ or 6″ in diameter. Under this condition *F* is surrounded by a disk of light several seconds in diameter and slightly yellowish. When *F* is in perfect focus it is clear cut and sharp, with no traces of a nebulous glow about it; the *Nova* is then surrounded by a similar mass of light to that previously shown by *F*, except that it is whitish.

"When I examined the *Nova* on August 19, 1892, I stated that it was apparently nebulous before I knew of any spectroscopic or other observations indicating a nebulous condition."

MT. HAMILTON, April 9, 1894.

I have nothing to add to or to subtract from the above statement, further than to say that on the morning of August 20, 1892, both Professor Campbell and myself independently announced to Professor Holden that this star was nebulous, from the previous night's observations, one with the spectroscope and the other visually, and each without knowing of the work of the other. Indeed I knew nothing of the spectroscopic observations until the evening of August 20.

A continuation of my measures of the position of Nova Aurigae, referred to above, will be found in *A. N.*, No. 3279, **137**, 233.

E. E. BARNARD.

YERKES OBSERVATORY,
March 21, 1897.

ERRATA.

The following corrections should be made in Professor Harzer's article in the January 1897 number of this JOURNAL:

Page 36, second line from the top, for *vigor* read *rigor*.

Page 37, for Δ read 1 (three times).

DR. ARENDT'S SPECTROSCOPIC INVESTIGATION OF THE VARIATION OF AQUEOUS VAPOR IN THE ATMOSPHERE.[1]

In the review by Professor E. B. Frost in the February number of the ASTROPHYSICAL JOURNAL, of Dr. Arendt's paper on the spectroscopic observation of variations of the amount of aqueous vapor in the atmosphere, there is a very serious error which should be corrected.

The statement is made that the increase in intensity of atmospheric lines in the spectrum is proportional to the increase in path. Probably what is meant is that the increase in intensity is as the increase in amount of atmosphere traversed by sunlight. But this statement not only supposes that the character of the distribution of aqueous vapor in the Earth's atmosphere is the same as that of the other gases, which is very far from being true, but that the increase in intensity of absorption should be as the increase in the amount of the absorbing gas traversed by sunlight, which is directly contrary to the law of absorption in which the absorption factor enters as an exponential term.

In my paper[2] it was thought best not to enter into these matters to any great extent, but this subject was carefully investigated and the value of the absorption factor for oxygen lines was determined, and the theoretical values of the intensity of oxygen lines at different altitudes of the Sun were calculated and compared with the results of observation, and they were found to agree within the limits of errors of observation.

In the case of water-vapor, the absorption factor was determined only approximately by an indirect method which consisted in plotting together the intensities (reduced to the standard condition of the Sun in the zenith), for a large number of days, when complete series of observations were secured, and the absolute humidity for those days. The result was not a straight line but somewhat of a curve, as it should be according to absorption laws; but any such determination can be but unsatisfactory because of the probable difference in the character of the distribution of aqueous vapor in the atmosphere during warm and cold weather.

[1] "Die Schwankungen im Wasserdampfgehalte der Atmosphäre auf Grund spectroskopischer Untersuchungen." Th. Arendt, *Wied. Ann.* **58**, 171–204, 1896.

[2] *Ap. J.* **4**, 324, 1896.

It was also shown by the investigation that if the absorption be supposed to increase proportionately with the amount of vapor traversed, no possible method of distribution of aqueous vapor in the atmosphere will give results agreeing with those of observation, while if the value of the absorption factor found be taken, then rational methods of distribution of aqueous vapor in the atmosphere will give results agreeing fairly well with observations. But the character of the distribution not only varies very greatly with the season, but is vastly different from that of the oxygen and nitrogen in the atmosphere, except during the prevalence of cold waves, when there is considerable resemblance. As this work was very laborious, and it was hoped before long to obtain special observations which would give accurate data for determining the value of the absorption factor for aqueous vapor free from the uncertainties of indirect methods, these comparisons were only carried out far enough to get a good idea of the facts in the case.

Professor Frost is mistaken in supposing that Dr. Arendt's method of comparing atmospheric and solar lines was different from mine. The method which he used (in 1895) was used by me during 1892 and 1893, and the method of comparison, together with a description of a photographic scale for determining the relative intensity of the solar lines used for comparison, and some of the results of observation obtained, were described in a paper read by Dr. J. S. Ames at the Congress of Astronomy and Astrophysics in Chicago, August 1893, and published in *Astronomy and Astrophysics* for November 1893.

The essential difference in the methods pursued by Dr. Arendt and myself were that I carefully determined the intensities of the solar lines used for comparisons by the aid of a photographic scale, the lines of which varied uniformly in intensity according to an exact law, and which closely resembled in appearance the spectrum lines which were measured.

In observations of the oxygen lines comparisons were made with selected solar lines (the intensities of which had been determined by the photographic scale) and also directly in the spectroscope with the lines of the scale, and the two methods gave concordant results. Some observations of the water-vapor lines have also been made in the same way, and as a result of comparison of the two methods, I can say that a direct comparison with the lines of the scale gives far more accurate results and is much more simple and satisfactory in every way. However, measurements of three or four solar lines of different intensity

should be made at the same time to obtain the slight corrections which are necessary where the width of the slit does not remain constant.

Had all of my observations been made in this direct way, greater accuracy would have been secured and an enormous amount of time and labor in the work of reduction would have been saved.

For determining the intensity of the comparison solar lines, Dr. Arendt's method of intensity steps gauged by the eye alone is certainly far from satisfactory where much accuracy is desired, as it is little better than guess-work, for the eye is quite unreliable for estimating how great differences in intensity are, though quite accurate for determining equality.

The principal reason why a spectroscope is not to be recommended as an addition to the instrumental equipment of all meteorological stations for prediction purposes, is that a set of observations, from sunrise to noon or from noon to sunset, is necessary for determining the data desired ; or if observations are confined to those made near the meridian, they may not be strictly comparable with the meteorological observations which are made in the morning and evening, and in point of time are not available for prediction purposes. At selected stations, however, meridian observations might be of value.

However, for purposes of studying the distribution and amount of aqueous vapor in the atmosphere, I believe the spectroscope is capable of giving much valuable and readily secured data, after the value for the absorption factor of aqueous vapor has been determined. Plans have been made which it is hoped will lead to the securing of this data before very long.

LEWIS E. JEWELL.

JOHNS HOPKINS UNIVERSITY,
March 10, 1897.

Reviews.

PHYSICAL PROPERTIES OF X-RAYS.

ALTHOUGH many new properties of these rays have been discovered during the past year, as yet no crucial experiment has been brought forward to decide whether they are longitudinal or transverse waves, or streams of material particles like the cathode rays. That they are streams of material particles is, however, unlikely in view of the experiments of Minchin and Threlfall. The ulcerations of the skin and injurious effects on the joints, which have resulted, in some instances, from long continued exposure to the Röntgen rays, have probably no connection with these rays, but may be due to the cathode rays outside the tube. The possibilities of longitudinal vibrations in the ether have been discussed by Professor J. J. Thomson (*Proc. Phil. Soc., Cambridge*, Vol. IX, Part II) in which he shows that when convection currents exist, the condition for the vanishing of the longitudinal wave is not satisfied, and in this case we may have longitudinal waves. These conditions exist in a vacuum tube, and would even exist in solid dielectric media, provided each molecule were made up of a pair of oppositely charged atoms. The necessary condition for the production of these waves being (1) that we should have means of producing waves whose length is comparable with molecular distances and (2) that we should be able to set the ether in motion. Both convection and longitudinal dielectric waves require for their propagation the presence of matter-carrying charges, for on Maxwell's electromagnetic theory the longitudinal wave could not be propagated in ether free from matter.

On the other hand, Professor Thomson (B. A. Address, *Nature*, September 17, 1896) has called attention to the fact that nearly every property of these rays is possessed by some form or other of light. For instance, many of the properties of these rays are possessed by a radiation emitted by the uranium salts and other fluorescent substances. This new radiation, which was recently discovered by Becquerel, is undoubtedly light, as it can be polarized. So far, the two essential properties of light waves, refraction and polarization, seem

to be absent from the Röntgen rays; but the absence of refraction is not uncommon even in ordinary light. As we know from the experiments of Kundt, Pflüger, and others, certain waves can pass through gold, silver, copper, and the aniline dyes without experiencing any refraction, while other waves are bent in the wrong direction. Professor Thomson also calls attention to the fact that according to our theories of dispersion we should not expect to find any refraction if the frequency of these waves is very great. Thus, on the Helmholtz dispersion theory, which is based on the assumption that a molecule of the refracting substance is composed of two oppositely charged atoms and that the specific inductive capacity of the medium may be considered as made up of two parts, one due to the ether itself, and the other to the setting of the molecules along the lines of electric force, we should find that the index of refraction increases with the frequency of the light waves until it is equal to the natural period of vibration of the molecules of the refracting substance. The index of refraction then diminishes, becomes less than unity, and finally approaches unity, as the period of the light waves becomes great in comparison with the free period of the molecules. The relation between the refractive index and the frequency is shown by the following consideration: Let a force of given amplitude act on a mixture of such molecules as are considered in the Helmholtz theory and which have but one natural period of vibration. Then beginning with a frequency of force less than that of the substance, the index of refraction will increase with the increase in the frequency of the force, because the specific inductive capacity increases, due to the fact that more and more of the molecules will swing into line; the effect of the force will be greatest when its period is equal to the natural period of the molecules. After this, as the period of the force becomes greater than the natural period of the molecules, they will topple over so as to oppose the specific inductive capacity due to the ether. If there are a sufficient number of molecules they may overcome the specific inductive capacity due to the ether, so that the specific inductive capacity of the mixture will be negative. Waves of this frequency could not, of course, traverse the medium, but would be totally reflected. Then, as the frequency of the force increases, the effect of the force in making the molecules set will be less and less, and finally the negative part of the specific inductive capacity of the molecules will equal the positive part due to the ether. The index of refraction will then be zero. After this the effect of the

force growing less and less with increase in frequency, the specific inductive capacity approaches that due to the ether alone, *i. e.*, unity.

So far the only experimenters who have obtained any evidences of polarization are Prince Galitzine and Karnojitsky (*C. R.* **122**, pp. 717–718, 1896). By a sort of cumulative method they thought they could observe slightly greater absorption with the axes of the tourmaline plates crossed than when the axes were parallel, but these experiments are uncertain and have not been confirmed by other observers. The reason we have not been able to detect any evidences of polarization may be due to the fact that we have not used polarizers of sufficiently fine structure. Long electric waves may be polarized by a very coarse wire grating; DuBois and Rubens succeeded in polarizing the infra-red rays by means of a fine wire grating; while shorter waves would require a very much finer structure.

Thus the absence of polarization and refraction cannot be urged as evidence against the theory that the Röntgen rays are transverse ether waves, but is rather what we should expect if these are very short waves. If the atoms of a vibrating molecule carry an electrical charge, then the electromagnetic theory of light would lead us to expect two kinds of waves, one due to the oscillations of the atom, the other due to the oscillations of the electrical charges carried by these atoms. The wave-length of the latter would be comparable with atomic dimensions. Professor Thomson asks: "Can these be Röntgen rays? and if so we should expect them to be damped with such rapidity as to resemble electrical impulses rather than sustained vibrations."

Professor Stokes thinks (*Nature*, p. 427, 1896) that the many properties which the Becquerel rays have in common with the Röntgen rays almost establishes the fact that the Röntgen rays are due to some kind of transverse vibration. He regards the disturbance as non-periodic, though having certain features in common with a periodic disturbance of very great frequency.

Nearly all observers who have studied the reflection of Röntgen rays were unable to detect any evidence of regular reflection. The only observer who has obtained any result indicating regular reflection is Lord Blythswood (*Proc. R. Soc.*, March 1896). He used two mirrors of polished speculum metal placed side by side to reflect the rays. The negative on development appeared to show the crack separating the mirrors. It may be worth while repeating the experiments using mercury as the reflecting surface. The diffuse reflection may be due

to the fact that surfaces which we regard as highly polished and which reflect waves of ordinary length, may in reality be extremely rough for these very short wave-lengths, or else it may be due, as Stokes suggests, to a kind of phosphorescence produced in the substance of the mirror. The latter view would seem to be supported by some experiments of Thomson in which the reflected rays appear to have different properties (as regards the discharge of electrified bodies) from the incident rays.

M. Gouy (*Jour. de Phys.* 3^{e} série, t. V) in his researches on the refraction and diffraction of the Röntgen rays made use of a form of tube called focal, in which the rays take rise at the surface of a thin plate of platinum placed at the center of curvature of a spherical cathode. The Röntgen rays which start from this flat lamina have a nearly equal intensity in all directions, down to the plane of this lamina. By working thus at very nearly grazing angle he obtained practically a linear source of great intensity, and was thus enabled to place his photographic plate at considerable distance with a reasonably short exposure. He stretched two platinum wires, whose diameter was $0^{mm}.040$, parallel to one another, and at a distance apart of 2^{mm}. Two prisms were placed near the middle of the wire, one opposite each wire, with their refracting angles turned in opposite directions. The two ends of the wire will thus be formed on the photographic plate by the rays which only traversed the air, while the central portion is formed by the rays which have traversed the prisms. The photographs were then mounted on a very accurate dividing engine, and examined for any displacement of the central part of the lines relatively to the two ends. In this way he was enabled to show that, for the transparent substances examined (glass, ebonite, aluminium, etc.), the index of refraction exceeds unity by less than .000001. For the more opaque substances, like Zn and Fe, the accuracy of the experiment is only about one-twentieth of the above. To obtain an idea of the possible wave-length, M. Gouy made use of a well-known diffraction experiment. A slit $0^{mm}.045$ in width was placed at a distance $2^{m}.5$ from a photographic plate on one side, and at an equal distance from the linear source of Röntgen rays on the other side. At a distance of $0^{mm}.055$ from the center of the resulting photograph of the diffraction slit the intensity is far less than one-fourth the maximum intensity. By calculating the wave-length of light which would give as rapid a falling off in intensity as this, he finds that it must be far less than 50.

This experiment, therefore, seems to show that the wave-length of these rays (if they are waves) must be less than $\frac{1}{100}$ that of ordinary green light.

L. Fomm (*Wied. Ann.*, No. 10, 1896), by a somewhat similar experiment with a diffraction slit, places the upper limit of the wave-length at 140. G. Sagnac (*C. R.*, **122**, No. 13) uses a wire grating and calculates from a scarcely measurable widening of the image of the slit an upper limit of 400.

Professor Thomson has, by the use of interference fringes, endeavored to detect any motion of the ether near an electric vibrator. As this motion would be oscillatory, and for an undamped vibrator the average velocity would be zero, he has used a heavily damped vibrator, hoping thus to obtain an average velocity which would be finite. The experiment gave a negative result. A similar experiment to detect any motion of the ether around a tube sending out Röntgen radiations was carried out, but failed to show any evidence of ether motion. A similar experiment has been made, independently, by Threlfall and Pollock (*Phil. Mag.*, December 1896) by an application of Michelson's interference experiments. They were unable to detect any shift of the interference bands when the Röntgen radiations were started and stopped. From the limit of accuracy imposed by the conditions of the experiment, they were led to the conclusion that Röntgen radiations are not associated with ether velocities exceeding 177^{m} per second, which is one thousand times less than the velocity of the cathode rays according to the measurements of Professor Thomson.

Among the most noteworthy properties of these rays are their power of rendering all bodies, dielectrics as well as conductors, conductors of electricity (J. J. Thomson and J. A. M'Clelland, *Proc. Phil. Soc. Cambridge*, Vol. IX, Pt. II). A gas which has been thrown into a conducting state by the passage of Röntgen rays, retains for a considerable time its power of discharging electrified bodies. This condition is destroyed if an electric current be passed through the gas. The gas while in this state behaves like a dilute solution of an electrolyte. When a current is sent through a gas which is being exposed to Röntgen radiation, the current destroys and the rays produce the structure which gives conductivity to the gas. When the rate of destruction is equal to the rate of production we have a saturation current, and any further increase in the E. M. F. can cause no further increase in the current. The conducting property which these rays

confer on gases is not destroyed when the gas is passed through metal tubes raised to red heat; it is, however, filtered out, as it were, by passage through water and glass wool. This latter, together with the comparatively slow migration velocity obtained for "ions" of a gas in this state conveying a current, has led Professor Thomson to think that the conducting structure is of a coarse nature, and that we are here perhaps dealing with aggregations of molecules rather than with the more simple ion used to explain electrolytic phenomena (J. J. Thomson and E. Rutherford, *Phil. Mag.*, No. 258). An experiment was made to determine if these rays were generated when the phosphorescence of the glass was produced by other means than the discharge from a negative electrode (Thomson, *Proc. Phil. Soc. Cambridge*, Vol. IX, Part II). For this purpose intense phosphorescence of the glass was produced by a ring discharge in an electrodeless bulb. In a second experiment this tube was filled with oxygen, which itself becomes phosphorescent, but in neither case was any effect observed on the photographic plate. It is, therefore, possible to have phosphorescence without the presence of Röntgen rays. Another experiment was carried out to see whether a negative electrode could produce these rays without the presence of the walls of the tube. For this purpose a piece of photographic plate was enclosed in a small ebonite box and placed inside the tube between the negative electrode and the wall of the tube, but in this case also no effect was produced on the photographic plate.

There is a general agreement among observers that the Röntgen rays discharge bodies, whether electrified positively or negatively; some, however, seem to have obtained evidence of an independent electrification due to the rays, without agreeing as to the sign of this electrification. Gerchun and Borgman find it negative, and Righi positive. Benoist and Hurmuzescu (*Jour. de Phys.*, **5**, pp. 358–362, 1896) have repeated the experiments with an improved form of electroscope, and also with an electrometer, but fail to find any evidence of such electrification. Lord Kelvin (*Nature*, December 31, 1896), by an experiment on air, unelectrified to begin with, finds that if such air be exposed to the Röntgen rays it shows decided negative electrification.

Benoist and Hurmuzescu find that the rate of discharge of electrified bodies depends not alone on the intensity of the radiation, but also on the nature of the charged surface. This is similar to the action of ultra-violet light, whose power of discharging bodies also depends

on the nature of the surface, but the order of the metals is not the same in the two cases. For the Röntgen rays the most opaque metals (Pt, Hg, etc.) come at the top of the series, *i. e.*, they are discharged most rapidly, while the metals which are discharged more slowly are the transparent ones like aluminium. From this arrangement of the metals they conclude that the power of the different metals for utilizing the energy of the rays for the dissipation of electricity varies inversely as their transparency. The theory of the pulverization of the metals has been used to explain the phenomena in the case of ultra-violet light, but this is scarcely applicable here, for similar effects were observed when the metals were imbedded in solid dielectric media, such as paraffine. In the investigation of the effect of the surrounding gas, they find that for the same gas at different pressures, or different gases at the same pressure, the rate of discharge is proportional to the square root of the density,

Another interesting property of the Röntgen rays has been pointed out by Aubel (*Jour. de Phys.*, **5**, November 1896) who has compared the diathermanous property of bodies and the transparency to these rays. He calls attention to the fact that the presence of the halogens and of sulphur in a molecule increase its diathermancy but renders it more opaque to the rays; while bodies containing the elements carbon, hydrogen, and oxygen allow the rays to pass readily, although they absorb strongly heat radiations. Comparatively thick layers of vapor, however, of such opaque substances as chloride of thallium seemed absolutely transparent.

Mr. C. T. Wilson, by studying the effect of Röntgen rays on cloudy condensation (*Proc. R. Soc.*, March 1896), finds that, while air exposed to the Röntgen rays requires to be expanded just as much as ordinary air in order that condensation may take place, these rays have the effect of greatly increasing the number of drops formed and the time during which the fog remains. In ordinary air the fog settles down in a few seconds, while in the air exposed to the rays it persists for some minutes.

Cajori (*Amer. Jour. Sci.*, **2**, 152), who exposed photographic plates, suitably protected from moisture and light, on the top of Pike's Peak, failed to detect any evidence of the Röntgen rays in solar radiation. Similar results have been obtained by Lea (*Amer. Jour. Sci.*, **1**, 363–364, 1896) and others.

Winkelmann and Straubel (*Wied. Ann.*, No. 10, 1896) found that

when the Röntgen rays strike upon a plate of fluor-spar and also upon glass containing certain of the rare earths, especially zirconium, they give rise to what they briefly call spar rays. They have studied the spectrum of the spar rays and find that it begins at $\lambda = 3960$, is a maximum at 2800, and ceases at 2330. By placing a piece of spar below the photographic plate they obtain effects many times stronger than if the Röntgen rays alone acted; if a thin sheet of paper is slipped between the sensitive layer and the fluor-spar, its effect is cut off, thus showing that the Röntgen rays that struck upon the surface of the spar must have given rise to new waves, for, had the Röntgen rays been simply reflected, the paper would not have cut them off. Similar effects from phosphorescent sulphide of zinc, have been observed by Henry (*C. R.*, **122**, 312–313, 1896). Henry has also found that when a zinc sulphide screen, wrapped in carbon paper, is covered with the object to be examined and exposed to the radiation of a Crookes' tube for some minutes and then removed to a dark room, the image shines for at least one quarter of an hour, so that the smallest details of the image can be made out. The light emitted by glowworms was found to be capable of penetrating blackened paper and affecting a photographic plate.

Experiments by M'Clelland (*Proc. R. Soc.*, No. 360) and others seem to show that the Röntgen radiations from a vacuum bulb are not homogeneous. By measuring the relative transparency of some substance, *e. g.*, glass and tinfoil (by passing the rays through them and observing the rate at which conductors are discharged in the two cases), and then measuring the relative transparency of the same two specimens after the rays have passed through a few additional sheets of tinfoil, it was found different in the two cases. This can only be explained by assuming that the rays are not homogeneous, and some are more readily absorbed by the glass and others by the tinfoil.

In an article by T. C. Gilchrist (*Bull. of the Johns Hopkins Hospital*, **8**, No. 71) the effect of the Röntgen rays on the skin and joints is fully discussed. Of the thousands of experiments that have been made with these rays only twenty-three are known to have been followed by injurious effects. In several of these cases the injurious effects have resulted from short exposures.

C. W. Waidner.

Johns Hopkins University,
February 25, 1897.

Über die ultravioletten Funkenspectra der Elemente. Sitzungsberichte d. K. Akad. d. W. Wien. Bd. **105,** pp. 389–436, 503–574, 707–740, 1896. FRANZ EXNER und E. HASCHEK.

THESE three papers describe a series of measures on more than nineteen thousand ultra-violet lines in the spark spectra of the following eleven elements, viz., Ag, Cu, Mn, W, Mo, Pt, Pd, Ir, Rh, Ru, Os. The spectra were photographed in the ordinary way with a Rowland 5-foot concave grating. Practically all the measures lie between λ4700 and λ2100. The blue and violet of the first order spectrum were separated from the ultra-violet of the second order by placing a glass plate so as to cover one-half of the slit. On the part of the photographic plate affected by the uncovered portion of the slit, one has the lines of both orders; while the light which passes through the glass belongs to the first order.

One is naturally curious to learn in what manner the stupendous task of measuring nineteen thousand wave-lengths was approached. Nothing could be simpler. Several methods, we venture to think, might be more accurate. The spectrum to be measured, together with its comparison spectrum, Iron, was projected upon a screen, the image being thirty times larger than the original. On the screen is a half-centimeter scale; this scale is so adjusted that the reading of each of the Rowland standards is its correct wave-length. The unknown wave-lengths are thus interpolated and their values read directly from the scale. By this convenient method, the authors think they have determined their wave-lengths with an error not exceeding 0.1 Ångström unit. They compare their values for 132 Osmium lines with those of Rowland and Tatnall for the same lines, and find the average deviation 0.03 Ångström unit. The results are, therefore, perhaps more accurate than one would imagine when he remembers that the physical width of the line, the grain of the plate, and (between standards) the distortion of the projection-lens, all cut a figure in this method. A series of wave-length determinations possessing this degree of accuracy (0.03 to 0.1 Ångström unit) is of great value. It is the more to be regretted, therefore, that the values are given only to the first decimal place, in contravention to the usual practice of giving results to one place beyond where they are considered thoroughly trustworthy.

Accompanying the text, are beautiful photogravure reproductions

of nearly all the spectra studied. Each strip includes about 700 Ångström units, and is about seven inches long. The separation of the overlapping spectra of different orders is excellently shown on these plates. H. C.

COLOR-PHOTOGRAPHY.

1. *Presidential Address.* W. LECONTE STEVENS. *American Association for the Advancement of Science*, **44**, 45, 1895.
2. *Zur Photographie in naturähnlichen Farben.* P. GLAN. *Wied. Ann.*, **58**, 402.
3. *On a Method of Photography in Natural Colors.* J. JOLY. *Nature*, p. 91, November 28, 1895.
4. *On Color Photography by the Interferential Method.* G. LIPPMANN. *Proc. R. Soc.*, **60**, 10.
5. *Photography in Colors. Nature*, p. 318, February 4, 1897.
6. *Photographic Reproduction of Colors. Nature*, p. 422, March 11, 1897.

IN the first of these papers we find an account of the work on color-photography up to the year 1895. Of the various methods described, the one perfected by F. E. Ives (*Jour. Franklin Inst.* **125–135**) is the most satisfactory. He takes three negatives through three compound color-screens, each adjusted by experiment so as to transmit in the correct proportion all the colors that go to make up one of our primary color sensations. From each of these negatives he prints a positive and dyes the positive red, green, or blue-violet according to the color sensation corresponding to its negative. When such a set of positives are superimposed and viewed by transmitted light we see an exact likeness, in its natural colors, of the object photographed.

In the second paper Glan suggests that, instead of color screens, a direct vision spectroscope might be placed in front of the lens of the camera. Then by a suitable arrangement of diaphragms in the spectroscope we could photograph the object in any colored light desired. Since Ives has shown that we must employ screens of compound, and not of pure colors, I think his method is preferable to Glan's.

Joly's method is based upon the same principle as that of Ives, but he combines the three photographs in one. He takes his negative

through a screen ruled alternately with orange, green, and violet lines. From this he prints a positive, and views the positive through a similar screen ruled in red, green, and violet. When this screen is so adjusted that the red lines are over those parts covered in the negative by the orange lines of the taking screen, the green and violet will lie over the green and violet portions, and if the lines are close enough together, the photograph will appear colored. He rules 300 to 1000 lines to the inch.

Lippmann employs a transparent photographic film, which he backs with a layer of mercury. The light reflected from the mercury interferes with the incident light so as to form standing waves in the film. Under these conditions the reduced silver forms parallel layers whose distances apart at any point are equal to one-half the wave-length of the light incident there. Thus the film is converted into a kind of reflecting grating, and when viewed at the angle of specular reflection, appears colored.

The last paper describes the results of a process of color photography invented by M. Villedieu-Chassagne. He washes an ordinary photographic plate in a colorless solution, takes a negative upon it, and from this he prints a positive upon a similarly prepared plate. Neither negative nor positive is colored, but the positive has the power of absorbing certain dyes in the correct proportions to give the natural colors of the object photographed. The natures of the solution and dyes have not yet been made public.

During an address before the Society of Arts, Sir Henry Trueman Wood exhibited some transparencies taken by a secret process devised by Mr. Bennetto, of Newquay, in Cornwall. They are described as "much clearer than those obtained by the Chassagne process, and look almost like water color sketches." "The colors are imprinted on the plate just as are the light and shade in an ordinary monochrome photograph, and are directly visible to the eye, without any subsidiary apparatus."

N. E. Dorsey.

Johns Hopkins University,
March 11, 1897.

Recent Publications.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

CHRISTIE, HILLS, and TURNER. Report on the expedition to Japan to observe the total solar eclipse of 1896, August 9. M. N. **57**, 95–111, 1897.

COMMON, A. A. Report on the expedition to Vadsö, in Finmark, to observe the total solar eclipse of 1896, August 9. M. N. **57**, 112–116, 1897.

CORTIE, A. L. The heliographic coördinates of Sun-spots and Faculæ on the Stonyhurst drawings. M. N. **57**, 141–147, 1897.

HARZER, P. Ueber die Rotationsbewegung der Sonne. A. N. **142**, 253–255, 1897.

FÉNYI, J. Prominences observed on August 8, 1896. Ap. J. **4**, 263–264, 1896.

FÉNYI, J. Protubèrances du 8 août 1896. Mem. Spettr. Ital. **25**, 225–226, 1896.

LOCKYER, J. NORMAN. Total Eclipse of the Sun, April 16, 1893. Phil. Trans., **187**, 551–618, 1896.

LOCKYER, J. NORMAN. Report to the Joint Eclipse Committee on the expedition to Kiö Island. M. N. **57**, 116–117, 1897.

MASCARI, A. Osservazioni del Sole fatte nel Reale Osservatorio di Catania il 9 agosto 1896 da $5^h\ 15^m$ a $5^h\ 59^m$ (t. m. civ. de Greenw.) Mem. Spettr. Ital., **25**, 229–231, 1896.

MAUNDER, E. W. The level of Sun-spots. Obs'y **20**, 93–95, 1897.

RUNGE, C., and F. PASCHEN. Oxygen in the Sun. Ap. J. **4**, 317–319, 1896.

SYKORA, I. Les Protubèrances solaires observées en 1896 à l' Observatoire de Charkow. Mem. Spettr. Ital., **25**, 173–179, 1896.

SYKORA, I. Sur l'eclipse totale du Soleil du 9 août 1896 observées à Sükawaara en Laponie. Mem. Spettr. Ital., **25**, 219–222, 1896.

TACCHINI, P. Osservazioni solari fatte nel 3° trimestre del 1896 al R. Osservatorio Romano. Mem. Spettr. Ital., **25**, 235–240, 1896.

TACCHINI, P. Osservazioni solari fatte nel 4° trimestre del 1896 al R. Osservatorio Romano. Mem. Spettr. Ital., **25**, 157–161, 1896.

TACCHINI, P. Sulla distribuzione in latitudine dei fenomeni solari osservati al Regio Osservatorio del Collegio Romano nel 4° trimestre del 1896. Mem. Spettr. Ital., **25**, 165–170, 1896.

TACCHINI, P. Sulla distribuzione in latitudine delle facole e macchie solari osservate al Regio Osservatorio del Collegio Romano nel 3° trimestre del 1896. Mem. Spettr. Ital., **25**, 151–154, 1896.

TACCHINI, P. Sulla distribuzione in latitudine delle protruberanze solari osservati al Regio Osservatorio del Collegio Romano nel 3° trimestre del 1896. Mem. Spettr. Ital., **25**, 243–248, 1896.

WOLFER, A. Sonnenflecken-Relativezahlen. Meteorolog. Zeitschr, **13**, 444, 1897.

3. STARS AND STELLAR PHOTOMETRY.

INNES, R. T. A. Note on the magnitude of η Argus, 1896. M. N. **57**, 155, 1897.

PICKERING, EDWARD C. Stars Having Peculiar Spectra. New Variable Stars in Crux and Cygnus. Relative Motion of Stars in the Line of Sight. A New Spectroscopic Binary in Puppis. Ap. J. **4**, 369–373, 1896.

PICKERING, EDWARD C. The Algol Variable +17°4367. W. Delphini. Ap. J. **4**, 320–323, 1896.

PICKERING, EDWARD C. Eye-estimates of Stellar Magnitude. Ap. J. **4**, 305–306, 1896.

ROBERTS, ALEXANDER W. Notes on a Method of Determining the Value of the Light Ratio. Ap. J. **4**, 265–273, 1896.

ROBERTS, ISAAC. Evidence of the evolution of Stellar Systems. Knowl. **20**, 10–11, 1897.

5. PLANETS, SATELLITIES AND THEIR SPECTRA.

CHRISTIE, W. H. M. Observations of Occultations of Stars and of Jupiter, and of Phenomena of Jupiter's Satellites, made at the Royal Observatory, Greenwich, in 1896. M. N., **57**, 183–191, 1897.

DAVIDSON, CHARLES. A Possible Cause of Change on the Moon's Surface. Knowl. **19**, 278–279, 1896.

FLAMMARION, C. L'Atlas Photographique de la Lune. Bull. Soc. Astr. France, 49–58, February 1897.

GLITSCHER, KARL. Wie kann ein Fortschritt in der Selenographie ermöglicht werden? Sirius, **25**, 6–12, 1897.

KLEIN, HERMANN. Eine Neubilding auf dem Monde. Sirius, **25**, 2–6, 1897.

LOWELL, P. Determination of the Rotation Period and Surface Character of the Planet Venus. M. N. **57**, 148–149, 1897.

LOWELL, P. Mercury. M. N. **57**, 148, 1897.

LYNN, W. T. Ball's Supposed Discovery of the Duplicity of Saturn's Ring. Obs'y **20**, 98–99, 1897.

MAUNDER, E. W. The Lunar Metropolis. Knowl. **19**, 279, 1896.

SCHUR, W. Determination of the Diameter and Compression of the Planet Mars from Observations with the Repsold Heliometer of the Royal Observatory, Göttingen. M. N. **57**, 150–151, 1897.

SELLS, E. P. Remarks on the Physical Observations of Jupiter made at the Adelaide Observatory, 1884–1893. M. N. **57**, 152–154 1897.

TERBY, F. Observations de la Planète Mars. Bull. Soc. Belge d'Astr. **2**, 50–58, January 1897.

6. COMETS, METEORS AND THEIR SPECTRA.

DENNING, W. F. The Geminid Meteor-shower of 1896. Obs'y **20**, 99–100, 1897.

DENNING, W. F. Real Paths of 107 Meteors Observed during the Ten Years ending 1896, November. M. N. **57**, 161–169, 1897.

NIESSL, G. VON. Catalogue of Real Paths of Large Meteors. M. N. **57**, 170–180, 1897.

THOMPSON, G. C., and H. W. L. TANNER. Notes on Meteors Observed at Penarth, Glamorgan, on 1896, November 14. M. N. **57**, 158–160, 1897.

8. TERRESTRIAL PHYSICS.

EDITOR OF *Sirius*. Das Funkeln der Sterne. Sirius, **25**, 12–16, 1897.

JEWELL, L. E. The Determination of the Relative Quantities of Aqueous Vapor in the Atmosphere by means of the Absorption Lines of the Spectrum. Ap. J. **4**, 324–342, 1896.

MONCK, W. H. S. Some Luminous Appearances in the Sky. Pub. A. S. P. **9**, 33–36, 1896.

9. Experimental and Theoretical Physics.

Dufour, H. Action électrique des rayons Röntgen. Arch. de Genève [4] **1**, No. 7, 91, 1896.

Dufour, H. Tubes de Crookes et rayons X. Arch. de Genève [4] **1**, No. 7, 82, 1896.

Heen, P. de. Vérification expérimentale de notre théorie du tube de Crookes. Bull. Acad. R. Belgique [3], **32**, Nos. 7–8, 277–279, 1896.

König, Walter. Über Röntgen'sche Strahlen. Z. f. Elektrochemie **3**, Nos. 3–7, 54–61, 1896.

Lodge, O. The Surviving Hypothesis Concerning the X Rays. Electrician, **37**, Nos. 947–949, 370–373, 1896.

Perrin, Jean. Sur le mécanisme de la décharge des corps électrisés par les rayons Röntgen. Éclairage électrique, **8**, Nos. 31–39, 225–226, 1896.

Trouton, F. T. The Duration of X-radiation at each Spark. Chem. News, **74**, Nos. 1923–1927, 177, 1896.

Villari, E. Sulle cariche e figure elettriche alla superficie dei tubi del Crookes e del Geissler. Nuovo Cimento [4] **3**, No. 7, 359–364, 1896.

Wadsworth, F. L. O. Note on the Preparation of Phosphorescent Barium Sulphide. Ap. J. **4**, 308–309, 1896.

10. The Spectra of the Elements.

Maunder, E. W. Helium and Parhelium. Knowledge, **19**, 284–287 1896.

11. Photography.

Wilsing, J. Ueber die Lichtabsorption astronomischer Objective und über photographische Photometrie. A. N. **142**, 241–251, 1897.

12. Instruments and Apparatus.

Sayen, H. Lyman, and Elmer G. Willyoung. An Improved Automatic Interrupter for Induction Coils. Jour. Franklin Inst. **143**, 231–235, 1897.

Wadsworth, F. L. O. The Modern Spectroscope. XX. On a New Form of Fluid Prism without Solid Walls and its Use in an Objective Spectroscope. Ap. J. **4**, 274–277, 1896.

13. GENERAL ARTICLES.

KAYSER, H. On the Mode of Printing Tables of Wave-lengths. Ap. J. **4**, 306–307, 1896.

LANGLEY, S. P. Report on the Work of the Smithsonian Astrophysical Observatory for the Year Ending June 30, 1896. Report Sec. Smithsonian Inst., June 30, 1896.

TURNER, H. H. On Differential Refraction to Terms of Higher Order than the First. M. N. **57**, 133–140, 1897.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The Editors do not hold themselves responsible for opinions expressed by contributors.

The ASTROPHYSICAL JOURNAL is published monthly except in July and September. The annual subscription price for the United States, Canada and Mexico is $4.00; for other countries in the Postal Union it is 18 shillings. Correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago, University Press Division, Chicago, Ill.*

Wm. Wesley & Sons, 28 Essex St., Strand, London, are sole foreign agents and to them all European subscriptions should be addressed.

All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.*

Baker's Chocolate

made by

Walter Baker & Co. Ltd.,

ESTABLISHED IN 1780,

at Dorchester, Mass.

Has the well-known

YELLOW LABEL

on the front of every package, and the trade-mark "La Belle Chocolatiere," on the back.

None other Genuine.

Walter Baker & Co. Ltd.,

DORCHESTER, MASS.

WHEATLET

DELICATE
DELICIOUS
NOURISHING

A whole wheat Cereal Food without the objection of oatmeal.

Does Not Overheat the Blood
or irritate the stomach.

Makes muscle, bone and nerves.

All Good Grocers Keep It—if yours does not, send us his name and your order and we will see that you are supplied.

Made only by the
Franklin Mills Co., **Lockport, N. Y.**

PENNOYER SANITARIUM.

Established 40 years; situate upon spacious grounds, 75 acres, in the **most healthful** locality in the country; very accessible to Chicago—only an hour's ride away, the PENNOYER SANITARIUM offers to **health** and **rest seekers** the advantages of a first class hotel **plus** home comforts, experienced medical care, skilled nursing, baths, electricity, etc. Cuisine distinctive. Hot-water heat. For illustrated prospectus, list of patrons, etc., address,

N. S. PENNOYER, M. D., Manager,
KENOSHA, WIS.

Why not recuperate this Spring?

HEALTH! REST! COMFORT!

The Jackson Sanatorium

Dansville, Livingston County, N. Y.

Established in 1858. Most beautiful and commodious Fire Proof Building in the world used as a Health Institution. All forms of Hydro-therapeutics, massage, rest cure; electricity administered by skilled attendants. A staff of regular physicians of large experience; accommodations and service of highest class. Superior cuisine directed by Emma P. Ewing, teacher of cooking at Chautauqua. Do not fail to write for illustrated literature and terms if seeking **health or rest.** Address

J. Arthur Jackson, M.D., Secretary, Box 2003.

"Globe"

It is our business to aid your business by building your business furniture; Filing Cabinets, Files, Desks, and so forth.

Globe goods are the standard for high quality; they are leaders. Used and indorsed by thousands of business houses throughout America; those who know the best when they see it; those who know what's what.

Complete illustrated catalogue of Globe Filing Cabinets, Desks and Office Furniture tells everything — free; also primer.

THE GLOBE CO., Cincinnati, O.

EASTERN BRANCH; 42 Beaver Street, N. Y.

Business · Furniture · Filing · · · Cabinets · Desks · · · And · · · · Office · · · Appliances Are Best · ·

W. B. Conkey Company

341-351 Dearborn St.,
CHICAGO.

Printers,
Binders,
Engravers

PUBLISHERS OF
Hon. William J. Bryan's Great Book,
"THE FIRST BATTLE"

Designers and makers of...
Diplomas, Catalogues, Annuals
Special College Literature

(We refer to the University of Chicago.)

A Charming Book About Old Violins.

Violinists everywhere will hail with delight the beautifully printed and authoritatively written book about Old Violins, just published by Lyon & Healy, Chicago. The fact that this volume contains, as an appendix, a list of the old violins offered for sale by Lyon & Healy, does not detract from its literary value, It is safe to say that any lover of the fiddle might seek a long time before he could find another volume whose perusal would afford him such a fund of entertainment. The short biographies of the famous violin makers are wonderfully complete and comprise a host of fresh anecdotes that must prove vastly interesting to violinists, great and small.

("OLD VIOLINS"—272 PAGES—FREE TO VIOLINISTS ONLY. LYON & HEALY, CHICAGO.)

THE MORGAN PARK ACADEMY

OF

The University of Chicago.

A thorough preparatory school for both sexes. Twelve teachers, all specialists and college graduates. Eight buildings, athletic field, gymnasium. Library of 4000 volumes. Delightful situation, near enough the city for Chicago students to spend Saturday and Sunday at home. Preparation for The University of Chicago and all other Colleges and Universities. Life in houses under teachers' supervision. Introductory year for young pupils.

Calendar and full information address

CHARLES H. THURBER, Dean,
Morgan Park, Ill.

Why "Ideal"?

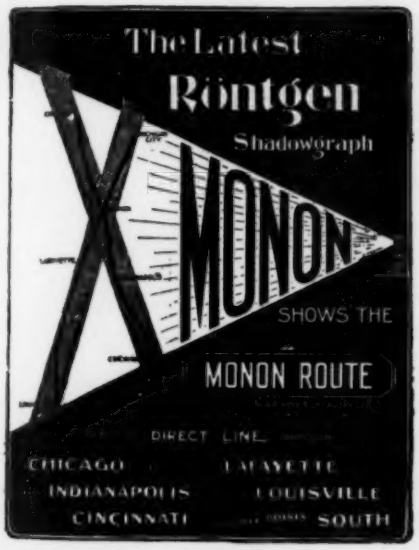
Because — it is easily filled, easily kept clean — the ink flows freely, but not too fast — any kind of writing may be done with it — and it is always ready for use. Good reasons for calling it . . .

Waterman's Ideal Fountain Pen

Money back if you want it.

Send at once for an Illustrated Price-list with testimonials (if your dealer will not supply you), and order of us. Mention **Scribner's.**

L. E. WATERMAN CO.,
(3 '96) **157 Broadway, New York.**



READERS

Will confer a favor upon the management by mentioning the "Astrophysical Journal" when writing regarding advertisements appearing in this journal

8 BEAUTIFUL ETCHINGS

ILLUSTRATING AMERICAN SCENERY AND AMERICAN ACHIEVEMENT ON "AMERICA'S GREATEST RAILROAD"

An Illustrated Catalogue

Containing miniature reproductions will be sent free post paid on receipt of one 2 ct. stamp, by George H. Daniels, Gen'l. Pass'r. Agt. Grand Central Station, New York.

COPYRIGHT 1896, BY GEORGE H. DANIELS, GENERAL PASSENGER AGENT

THE WASHBURN BOOK ABOUT MANDOLINS AND GUITARS.

Any one interested in the subject of mandolins and guitars can obtain a beautiful book about them free by writing to Lyon & Healy, Chicago. It contains portraits of over 100 leading artists, together with frank expressions of their opinion of the new 1897 model Washburn Instruments. Descriptions and prices of all grades of Washburns, from the cheapest ($15.00) upwards, are given, together with a succinct account of the points of excellence which every music lover should see that his mandolin or guitar possesses. Address, Dept. M, LYON & HEALY, 199 Wabash Avenue, Chicago.

THE WESTON STANDARD

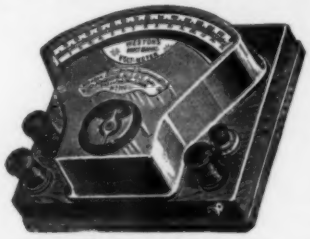
VOLTMETERS & AMMETERS

Portable,

Accurate,

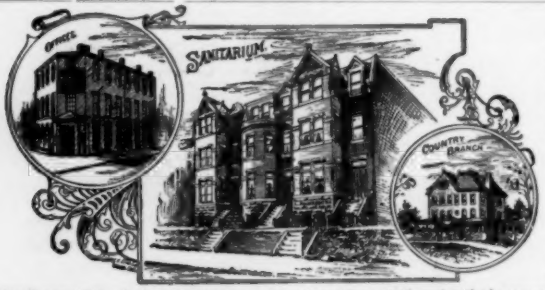
Reliable and

Sensitive.



WESTON ELECTRICAL INST. CO.,

114 WILLIAM ST., NEWARK, N. J.



The treatment consists of douches, showers, needle baths, and the water-cure treatment; galvanic, faradaic and static electricity; massage and muscle beating; Isopathy (animal extracts), and the necessary medicines; in fact, all recognized scientific methods for the cure of disease.

THE WASHINGTON SANITARIUM,

WASHINGTON, D. C.

The Medical Director is Dr. Mahlon Hutchinson, of the former well-known Hammond Sanitarium. The Medical Staff consists of six physicians, of national reputation in their several specialties. At the Country Branch there are Tennis Courts, Bowling Alley, etc., for the amusement of convalescents.

Special attention paid to the treatment of **DISEASES OF THE NERVOUS SYSTEM AND OF THE SKIN.** Charges moderate. **For full information and pamphlet,** Address

DR. MAHLON HUTCHINSON, 720 Fourteenth St., Washington, D. C.

The University of Chicago Journals

The Biblical World
Published monthly. $2.00 a year; foreign, $2.50. Single numbers, 20 cents.

The School Review
Published monthly (except July and August). $1.50 a year; foreign, $2.00. Single numbers, 20 cents.

The American Journal of Sociology
Bi-monthly. $2.00 a year; foreign, $2.50. Single copies, 35 cents.

The Journal of Political Economy
Published quarterly. $3.00 a year; foreign, $3.25. Single numbers, 75 cents.

The Journal of Geology
Published semi-quarterly. $3.00 a year; foreign, $3.50. Single numbers, 50 cents.

The Astrophysical Journal
Published monthly (except July and September). $4.00 a year; foreign, $4.50. Single copies, 50 cents.

The Botanical Gazette
Published monthly. $4.00 a year; foreign, $4.50. Single numbers, 50 cents.

The American Journal of Semitic Languages and Literatures
Published quarterly. $3.00 a year; foreign, $3.50. Single numbers, 75 cents.

The American Journal of Theology
Published quarterly. $3.00 a year; foreign, $3.50. Single numbers, 75 cents.

The Demand of the Age

PRACTICAL PERIODICALS FOR PRACTICAL PEOPLE

Edited by men of national reputation.

Commanding the thought of the ablest scholars of the United States and Europe.

All subscriptions, and business communications in reference to journals, should be addressed to

THE UNIVERSITY OF CHICAGO
University Press Division
CHICAGO, ILL.

All remittances should be made payable to THE UNIVERSITY OF CHICAGO

EASY TOUCH. UNIFORM WORK.

NO END OF GOOD POINTS ABOUT THE SMITH PREMIER.

"IMPROVEMENT THE ORDER OF THE AGE."

DURABILITY. BEAUTY OF DESIGN.

In Improvements—The Leader.
In Construction—Mechanically Correct.
In Operation—Simple and Satisfactory.

SEND FOR PREMIER NEW PICTORIAL CATALOGUE.

The Smith Premier Typewriter Co.

SYRACUSE, N. Y., U. S. A.

Branch Offices in 42 Principal Cities in the United States and England.

The **Unit of Value** in Typewriters is the

REMINGTON

It sets a known and tested **Standard** of excellence.

Everyone knows what it represents —the Best Work with Least Labor, Enduring Service, Unequalled Economy and Convenience. The...

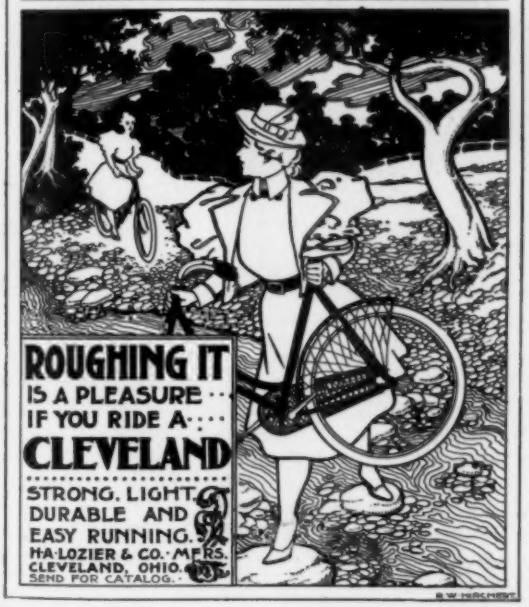
Number **6** Model

bears the stamp of

Unqualified Public Approval

Wyckoff, Seamans & Benedict, 327 Broadway, N.Y.

CLEVELAND BICYCLES



ROUGHING IT
IS A PLEASURE...
IF YOU RIDE A...
CLEVELAND

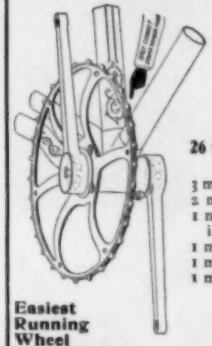
STRONG, LIGHT, DURABLE AND EASY RUNNING.
HA-LOZIER & CO., MF'RS.
CLEVELAND, OHIO.
SEND FOR CATALOG.

Send 4c. postage for our booklet, "Shakespeare and the Bicycle," Twelve special designs in colors by F. Opper, of "Puck." Mention this Journal.

THE *Racycle*

NARROW TREAD

ARE YOU GOING TO BUY A.. **Wheel**



Easiest Running Wheel in the Weird

26 RADICAL IMPROVEMENTS IN 1897 MODELS

3 models, single Roadsters	$100
2 models, Tandems - -	150
1 model extremely (3¾ in.) narrow tread -	100
1 model Racer - - -	125
1 model Gents' - - -	75
1 model Ladies' - - -	75

Send for Catalogue and Booklets

CHICAGO BRANCH
S. W. Cor. Wabash Ave. and Congress Street.

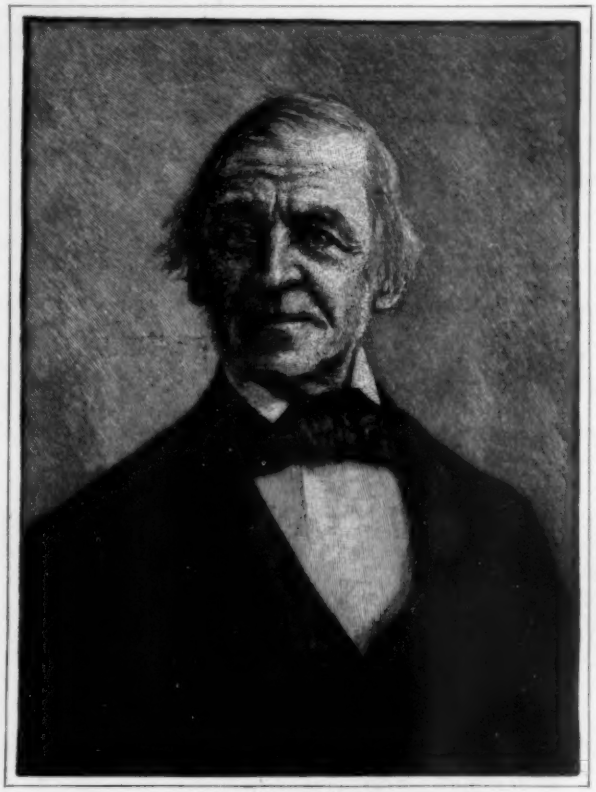
MIAMI CYCLE & MFG. CO., .. Middletown, Ohio

"A PROFESSOR OF BOOKS"—EMERSON

In glancing through one of the early volumes of Charles Dudley Warner's "Library of the World's Best Literature," we met, in the Emerson section, an extract from one of the sage's fine pages that ran in this wise:

"Meantime the colleges, whilst they provide us with libraries, furnish no professor of books; and, I think, no chair is so much wanted."

It is doubtful if any phrase could so happily describe at once the function and the achievement of Mr. Warner in his new and great work. He himself is essentially a "professor of books," although the charm of his work has tended to make us forget his wide and varied learning. And knowing not only books but living writers and critics as well, Mr. Warner has gathered around him as advisers and aids other "professors of books," not men of the Dryasdust school, but those who possess the same salient charm and graphic power as himself.



RALPH WALDO EMERSON

The result of this remarkable literary movement has been to provide the great reading public, the busy public of ever scant leisure, with just what Emerson declared more than half a century ago we so much needed, namely, a guide to the best reading.

Emerson indeed likens a library of miscellaneous books to a lottery wherein there are a hundred blanks to one prize, and finally exclaims that "some charitable soul, after losing a great deal of time among the false books and alighting upon a few true ones, which made him happy and wise, would do a right act in naming those which have been bridges or ships to carry him safely over dark morasses and barren oceans into the heart of sacred cities into palaces and temples."

This is precisely what Mr. Warner's new library does in the fine, critical articles which preface the master-works of the greatest writers.

Think what is here accomplished. In the case of Emerson himself, the general voice has proclaimed his two volumes of "Essays" a requisite for every library. But if we have the wish to go farther and know more of the work of our greatest man of letters, what volume shall we select? There are ten or eleven others to choose from. Looking into Mr. Warner's Library we find that Dr. Richard Garnett, of the British Museum, a life-long student and biographer of Emerson, has written a critique that gives us exactly what we wish to know.

Again, take the case of the man who occupies in German life the same place as the Sage of Concord in American life. All told, Goethe's writings comprise seventy compact volumes. Emerson himself, in one of those delightful letters he wrote to Carlyle, tells how, after years of effort, he has "he has succeeded in getting through thirty-five," and despairs of the other half! But who, even among those who call themselves well read, have despatched thirty-five volumes of the great German, or even half or third of thirty-five? Nevertheless,

"A PROFESSOR OF BOOKS"

we do not like to remain without at least a general and historical view of Goethe's tremendous activity, and, furthermore, if we go beyond "Faust" or "Wilhelm Meister," we are—the most of us—lost in a sea of conjecture as to which of the remaining sixty-eight volumes we shall attack.

How happily has Mr. Warner here come to our relief! He has chosen, to prepare the Goethe section for the Library, no less a scholar than Prof. Edwin Dowden of Dublin, the President of the Goethe Society of England. The assignment was most fitting, as no Englishman since Carlyle is so well versed in all that pertains to the great German, none knows better of his strength and power, none better his shortcomings and his weaknesses. Here we have the distilled essence of his criticism, together with Professor Dowden's choice of what is of paramount and lasting value in the legacy Goethe has left to us.

Professor Evans, of Munich, performs for us a like service with Schiller. Prof. Maurice Francis Egan does the same with Calderon. Prof. Charles Eliot Norton of Harvard with Dante. Prof. Santayana with Cervantes. The historian Lecky with Gibbon. Charlton T. Lewis with Bacon, and so on. Never, it seems to us, was so much talent, such an array of eminent names pressed into service for the production of such compact and pregnant exposition and criticism.

It would be a great mistake, however, to believe that the new Library which Mr. Warner and his associates have prepared has to do with nothing but the "classics." Here, for instance, is Dumas the elder. Who is there that has not fallen a victim to the stirring romances of "The Three Musketeers" and their extensive kin? Many of us, when we have once got into their companionship, hardly know where to stop. But we do not want to be misled into reading an immense number of worthless and mediocre stories that Dumas, in the burst of his fame, was led to palm off as his own, though they were in reality the work of others. There never was a more delightful "professor of books" than Andrew Lang, and we doubt if there is any one living who could tell us so much as he has told us in the Library of what is interesting and what we wish to know of Dumas.

We cross from the field of romance over into that of poetry, and the first name we chance upon is that of Wordsworth, one of the greatest poets who ever lived—no one questions that. And yet what great poet ever left so much fine wheat mixed with so much chaff? Dr. R. H. Hutton, the editor of the London *Spectator*, and one of the sanest and most appreciative of living critics, has chosen for this Library the best of Wordsworth's poetry, and has planned such further journeys through the poet's writings as the reader may wish to take.

And so we might go on. But we think we have made clear to the reader that which struck us so forcibly when we looked into the Emerson section, namely, how finely Mr. Warner has, in his Library, succeeded in satisfying the great want which Emerson there so well voiced—that of a "professor of books." Exactly as the professor of chemistry or physics or astronomy or biology gives the student a view of the whole field of his seience, the summary of its achievements, its great names and its great works, so Mr. Warner and his associates have given us the distillation not merely of the whole world's literature, in itself a colossal attempt, but, in addition, its history, biography, and criticism as well. It is only when we grasp its full import that we realize the truly vast and monumental character of the Library. It must assuredly rank as one of the most notable achievements of the century.

That there is a widespread desire among all classes to possess these thirty treasure volumes clearly appears from the number and the character of the letters which are coming from far and near to the Harper's Weekly Club, through which a portion of the first edition is being distributed.

Although the first edition is the most desirable because printed from the fresh, new plates, the publishers, instead of advancing the price, have actually reduced it nearly half, so as to quickly place a few sets in each community for inspection.

The demand for the most desirable first edition is so active and the number of sets allotted to be distributed is so limited, it is safest for those who really covet this invaluable Library of Mr. Warner's to write at once to Harper's Weekly Club, 91 Fifth Avenue, New York, for sample pages and special prices to members of the Club now forming, and which will close the last day of the present month.

THE CENTURY CO. announces an educational competition. It is on a most interesting and original plan. Thirty-five prizes amounting to $1,000 (first prize $500) will be given for the best answers to 150 questions. The topics selected deal with matters of general information; they are not scholastic, but are educational. Your training at school was only mental drill; you have forgotten all you learned there but "reading, writing and arithmetic." You will never forget the information derived from answering these questions, because every one deals with a living and useful fact. No cube-roots, no parsing, no memorizing of dates; instead the learning of things that everyone ought to know. If you make an honest attempt to win, you will learn to concentrate your mind, sharpen your wits, secure most valuable information, and stand a good chance of making $500 (perhaps $1,000: see below). If you gain first prize, the knowledge you have acquired will be worth more to you than the $500 you receive.

$1,000
in 35 Prizes

$500
First Prize

To find the answers to these questions you must use the encyclopedic material in The Century Dictionary and Cyclopedia, because these like thousands of others can best be answered by reference to this great work. If you do not already possess a set, you can easily procure one. A limited number of clubs are now being formed for the purchase of sets at the lowest wholesale price. Each person joining a club (and those who apply at once can join) secures his set at a reduction of 40 per cent. and has the further privilege of paying for it in small monthly payments. A first payment of $5 will bring you the work and enable you to try for the first prize of $500, as well as the supplementary prize of $500 more.

Small Monthly Payments

The 150 questions are divided into three sets of 50 each. A month is allowed to answer each set. Try them at home. They will be an intellectual recreation for you and your family; also a good test of your ability to deal with words and facts. Have your children try them: it will be a real education for them. Write to us for sample questions, to see how instructive and useful they are, or for a description of the work.

The Century Dictionary and Cyclopedia

$500 MORE. *We offer a further prize of $500 to the competitor who, laying aside The Century, succeeds most successfully in answering 90 per cent. of these questions from ten other works of reference, no matter in how many volumes each is published. This offer is made for the purpose of showing that The Century is superior not to any other one work of reference, but to any other ten.*

THE CENTURY CO., (Dept. Gs.) New York

THE SUMMER QUARTER

OF

The University of Chicago

WILL OPEN JULY 1, 1897.

This Quarter is an integral part of the scholastic year, and is divided into two terms of six weeks each.

Two hundred and twenty courses of Instruction in Philosophy, Pedagogy, Political Science, History, Sociology, Comparative Religion, Hebrew, Assyrian, Arabic, Egyptian, Old Testament Literature and History, New Testament Literature and History, Comparative Philology, Greek, Latin, Romance Languages and Literatures, Germanic Languages and Literatures, English, Mathematics, Astronomy, Physics, Chemistry, Geology, Zoölogy, Anatomy and Histology, Bacteriology, Palæontology, Botany, Public Speaking, Systematic Theology, Church History, Homiletics, and Physical Culture.

Instruction will be given by one hundred and one Professors and Instructors. All the Libraries, Laboratories, and Museums of The University will be open.

Expenses, including Tuition, for a term of Six Weeks, need not exceed $50.00, and may be less.

For circulars and information address,

THE EXAMINER,

THE UNIVERSITY OF CHICAGO, CHICAGO, ILL.

A FIRST CLASS LINE
FOR FIRST CLASS TRAVEL.

Chicago. New York. Boston.

A Summer Note Book

descriptive of the Summer Resorts of the North and East and how to reach them, revised and profusely illustrated, will be sent for 10 cents postage.

City Ticket Office, 119 Adams Street, CHICAGO.

O. W. RUGGLES,
Gen'l Pass'r and Ticket Agent.

Wanted

Copies of

The . . .

Astrophysical Journal

For

MARCH 1895

One Dollar each will be paid for clean and perfect copies of the above issue .

Address . . .

GEORGE E. HALE
Yerkes Observatory
Williams Bay, Wisconsin, U. S. A.

CHOICE ROSES at 5c.

We send instructions with each order: HOW TO PLANT AND CARE FOR THEM.

Our Rainbow Collection of 20 Roses for $1.00.

Prepaid by Mail

The Roses we send are on their own roots, from 10 to 15 inches high, and will bloom freely this Summer, either in pots or planted in yard. They are hardy ever-bloomers. We guarantee them to reach you in good condition. We also **guarantee them to be the best dollar's worth of Roses you ever purchased.**

Beaute Inconstante, changes color from yellow to red. **White Perle des Jardins**, immaculate white. **Md. Schwaller**, rich pink in clusters, very fragrant. **Maman Cochet**, rosy pink touched with yellow. **Henri Rignon**, coppery yellow, shaded with red. **Md. Scipion Cochet**, primrose yellow, rose shadings. **Bouquet d'Or**, deep golden yellow, great bloomer. **The Queen**, immense large pure white, very fragrant. **American Belle**, a grand deep red rose, deliciously fragrant. **Corinna**, flesh color, shaded tawny copper. **Crimson Queen**, deep velvety crimson, very rich. **Augusta Victoria**, pure white, always in bloom **Queen of Fragrance**, in clusters of 8 to 10 roses, white edged shell pink. **Princess of Wales**, amber yellow, tinged with copper and orange. **Madame Jules Finger**, pure snow white, wax-like in texture. **Princess Sagan**, called the velvety rose from its richness. **J. B. Varronne**, rosy pink, bordered with crimson. **Yellow Hermosa**, a charming yellow of the richest color. **Marquis de Viviens**, everybody's favorite, always in bloom. **Victor Hugo**, rich bright pink, finest rose grown.

Get up a club and get your collection free. Six Collections, all labeled and packed separately, sent for $5.00. Our Handsome, Illustrated Catalogue, describing all kinds of Roses, Plants, Bulbs, and Seeds, mailed for 10 cents, stamps. **We can save you money.** Liberal premiums to club raisers, or how to get your seeds and plants free. We are the **largest rose growers in the world.** Our sales of Rose Plants alone last season exceeded a million and a half. When you order Roses, Plants and Seeds, you want the very best. Try us. Address,

The GOOD & REESE CO. Box 6 Champion City Greenhouses Springfield, Ohio.

VOLUME IV NUMBER 5

THE PHYSICAL REVIEW

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS

CONDUCTED BY
EDWARD L. NICHOLS
ERNEST MERRITT, AND FREDERICK BEDELL

XXIII

MARCH–APRIL 1897

TABLE OF CONTENTS

The Lead Cell B. E. MOORE 353

The Influence of a Static Charge of Electricity upon the Surface Tension of Water E. L. NICHOLS and J. A. CLARK 375

On the Mechanical Conceptions of Electricity and Magnetism W. S. FRANKLIN 388

Monri Contributions: On a Possible Development of the Idiostatic Electrometer; *C. Barus.* Empirical Formulæ for Viscosity as a Function of Temperature; *A Wilmer Duff.* A Synchronous Motor for Determining the Frequency of an Alternating Current; *G. S. Moler.* Lecture-room Demonstration of Orbits of Bodies under the Action of a Central Attraction; *R. W. Wood.* The Refractive Index of Water and Alcohol for Electrical Waves; *A. D. Cole* 400

New Books: *Merriman and Woodward:* Higher Mathematics. *Hathaway:* A Primer of Quaternions. *D. C. and T. C. Jackson:* Alternating Current Machinery. *Kapp:* Transformers for Single and Multiphase Circuits. *Brentano:* Méthode et Principes des Sciences Naturelles. *Le Blanc:* Elements of Electro-Chemistry. *Carter:* Motive Power and Gearing for Electrical Machinery. Mathematical Papers read at the International Mathematical Congress, Chicago, 1893. *Williams:* Laboratory Manual of Inorganic Chemistry. *Tuttle:* Chemistry at a Glance. *Thorp:* Inorganic Chemical Preparations. The American Annual of Photography. *Matthews and Shearer:* Problems and Questions in Physics. 416

COPYRIGHT, 1897, BY THE MACMILLAN COMPANY.

PUBLISHED FOR CORNELL UNIVERSITY
NEW YORK: THE MACMILLAN COMPANY
LONDON: MACMILLAN & CO., LTD.
BERLIN: MAYER & MUELLER

THE JOURNAL OF PHYSICAL CHEMISTRY

Edited by
Wilder D. Bancroft, Joseph E. Trevor

Published at
Cornell University

RECENT ARTICLES

On Irreversible Cells. I.	*A. E. Taylor*
Chemistry and Its Laws	*F. Wald*
On Ternary Mixtures	*W. D. Bancroft*
Allotropy of Sucrose	*F. G. Wiechmann*
Nascent Hydrogen	*R. Franchot*
On Irreversible Cells. II.	*A. E. Taylor*
Purification of Water	*G. A. Hulet.*
Solution and Fusion	*W. D. Bancroft*
Speed of Esterification	*R. B. Warder*
Precipitation of Salts	*H. A. Bathrick*
Inner Thermodynamic Equilibria	*J. E. Trevor*
The Abegg Method, *etc.*	*E. H. Loomis*
Sulfur and Toluene	*J. K. Haywood*
On Quintuple Points	*W. D. Bancroft*
Solids and Vapors. Second Paper	*W. D. Bancroft*
Osmotic Pressure and Variance	*J. E. Trevor*

In addition to the original articles each number contains critical reviews of the current journal and book literature of Physical Chemistry.

ITHACA, NEW YORK: The Editors

LONDON: Gay and Bird
22 Bedford Street, Strand, W.C.
For the British Islands

LEIPZIG: Bernh. Liebisch
(K. F. Koehler's Antiquarium)
For the Continent of Europe

Issued every month, except July, August, and September: Price, $2.50 per year

The first volume will run to the close of 1897, and comprise twelve numbers

RECENTLY PUBLISHED

The Natural History and Scientific Book Circular
No. 124

ASTRONOMY

Including Works from the Libraries of

SIR G. B. AIRY, F.R.S., late Astronomer Royal
and
A. C. RANYARD, F.R.A.S., Editor of Knowledge

A new and valuable catalogue of astronomical and astrophysical works. To be had on application to

WILLIAM WESLEY & SON,

Agency of the Smithsonian Institution
U. S. Government Departments,
28 ESSEX STREET, STRAND, LONDON.

CARL ZEISS
OPTICAL WORKS, JENA

MICROSCOPES AND MICROSCOPIC ACCESSORIES

PHOTO-MICROGRAPHIC AND PROJECTION APPARATUS

PHOTOGRAPHIC OBJECTIVES AND PHOTO-OPTICAL APPLIANCES

MECHANICAL AND OPTICAL MEASURING INSTRUMENTS

[Abbe Spectrometer and Refractometer (the latter for scientific and technical purposes—Butter Refractometer, Crystal Refractometer, etc.), Focometer, Thickness Micrometer, Comparator, Spherometer, Dilatometer, etc. NEW INSTRUMENTS: Pulfrich Universal Refractometer, Spectroscopes, Goniometer, etc.]

NEW BINOCULAR HAND TELESCOPES

Catalogue mailed free on application

LOUIS MÜLLER-UNKEL,

(Partners: L. Müller-Unkel and R. Müller-Uri)

BRAUNSCHWEIG, GERMANY

MANUFACTURERS OF

Blown Glass
For Scientific Purposes

All kinds of Lecture Apparatus and Supplies

Lecher's and Zehender Tubes, etc.
For Hertz's Experiments

Lenard's Tube
For Kathode Rays

Röntgen's X Rays Apparatus
(Latest Improved Style)

Plucker's Spectrum Tubes and Geissler Tubes

Elster and Geitel's Apparatus
For Tela's Experiments

SOLE MAKERS OF

ELSTER & GEITEL'S PHOTO-ELECTRIC APPARATUS, etc.

Photographs, Bromide Enlargements, Lantern Slides, and Window Transparencies.

From recent Astronomical Negatives made by

Professors George E. Hale,
E. E. Barnard, and
S. W. Burnham,

including all that will be made at the

YERKES OBSERVATORY

Sun-Spots, Faculæ, Solar Prominences,

From negatives made with the

Spectroheliograph at the Kenwood Observatory

Stellar Spectra and the Spectra of various Solar Phenomena

Professor Barnard's Photographs of Comets, Nebulæ, and the Milky Way

Professor Burnham's Negatives of the Moon, Winter and Summer Views of Mt. Hamilton and Lick Observatory

Lantern-Slides furnished from any of the plates, diagrams, etc., published in this journal

Price of Lantern-Slides 75 cents each

Catalogue and Price List mailed on application

Chicago Institute of Photography

308-316 Dearborn Street

CHICAGO

GAYTON A. DOUGLASS
Director

JOHN BYRNE'S

Astronomical and Terrestrial

TELESCOPES

Of three, four, five, six inches and larger apertures

Short Focus and Brilliant Light

Inimitable for Perfection of Figure, Sharpness of Definition, and Accuracy of Color Correction. Send for Catalogue to

GALL & LEMBKE

Opticians

21 Union Square, New York City

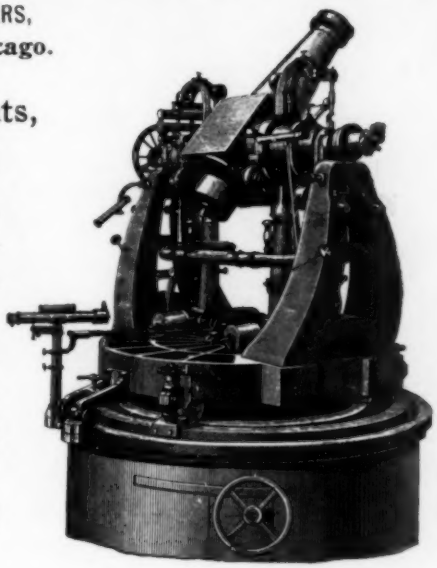
Kandler & Gaertner,

SCIENTIFIC INSTRUMENT MAKERS,
415-417 Dearborn St., Chicago.

Astronomical Instruments, Apparatus for Physical and Astrophysical Research.

Equatorials, Reflecting Telescopes, Universal Instruments, Zenith Telescopes, Spectrometers, Refractometers, Bolometers, Magnetometers, Galvanometers, Comparators, Cathetometers, Circular and Longitudinal Dividing Engines.

Instruments and Apparatus of any description carefully reconstructed or repaired.



ALVAN CLARK & SONS

CAMBRIDGEPORT, MASS.

Manufacturers of

ASTRONOMICAL TELESCOPES

With Improved Equatorial Mountings

Sizes from Four-inch Aperture
to the Largest Ever Ordered

Send for Photographs of our Portable Equatorials or five and six-inch fixed, with accessories — the best to be had for educational and amateur work.

Terrestrial Telescopes for private residences.

The performance of our instruments, famous the world over, is their own greatest recommendation. An experience of nearly a half century in the art of telescope making enables us to apply a degree of skill and judgment to our work which make our objectives **unrivalled in excellence.**

Among our telescopes are

The Lick Refractor, 36-inch.
Pulkowa Refractor, 30-inch.
Washington Refractor, 26-inch.
University of Virginia, 26-inch.
Princeton Refractor, 23-inch.
Denver Refractor, 20-inch.
Chicago Refractor, 18.5-inch.
Rochester Refractor, 16-inch.

Most Modern and Complete Illustrating and Engraving Establishment in America

Binner's "Modernized Advertising" sent on receipt of 10 cents postage. Illustrated from cover to cover.

Binner's Poster mailed to any address on receipt of 10 cents U. S. postage.

Illustrators and Engravers for

Scientific Reports and Publications, College Annuals, Souvenirs, Medical Books, Etc.,

Either in black and white or colors

Binner, in the Fisher Building, **Chicago,** Ill

John A. Brashear

ASTRONOMICAL AND PHYSICAL INSTRUMENTS

Allegheny, Pennsylvania

ASSOCIATES:

Dr. Charles S. Hastings

James B. McDowell

Charles H. Brashear

CABLE ADDRESS:
Brashear, Pittsburg

Manufacturers of

Refracting and Reflecting Telescopes, for visual and photographic purposes.

Objectives all computed by our associate, DR. CHARLES S. HASTINGS, and rigorously treated for all corrections.

Wide field Photographic Doublets, giving circular images of stars up to edge of field.

Plane Mirrors of Speculum Metal, Steel or Glass. Parallel Plates. Prisms of Glass, Quartz or Rock Salt, with surfaces accurately flat.

Eyepieces of any description.

Diffraction Gratings ruled on PROFESSOR ROWLAND'S Engine, from one to six inches in diameter.

Spectroscopes of all kinds, including various forms of Telespectroscopes, Spectroheliographs Concave Grating Spectroscopes, Spectrometers etc., for visual and photographic work.

Comet "Sweepers," Micrometers, Driving Clocks, Heliostats, Siderostats, Refractometers, etc., etc.

SPECIAL APPARATUS

For Astronomical and Physical Research Designed and Constructed

PLATE XIX.

S

P

F

VENUS.

1889, MAY, 29^{d} 11^{h} 12^{m} A.M.

12-inch Equatorial. E. E. Barnard.